

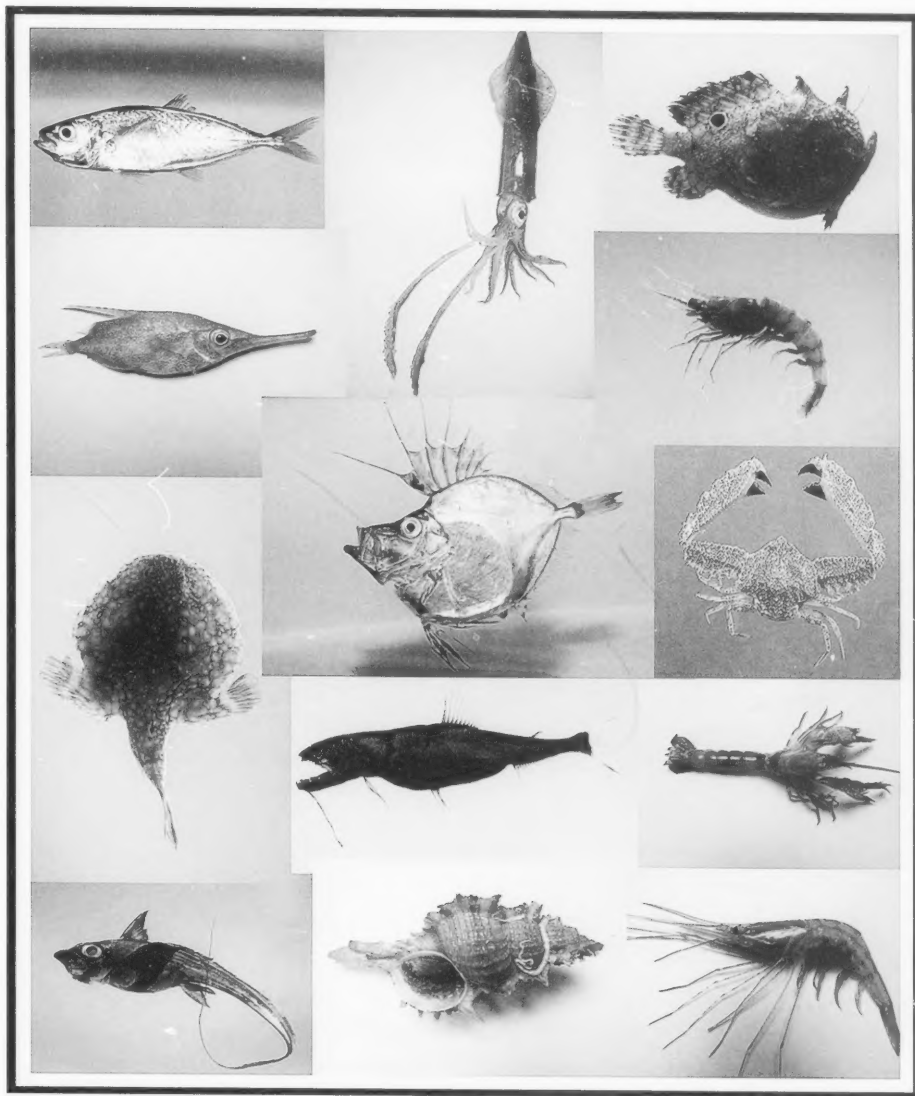


Marine Fisheries

REVIEW

Vol. 72, No. 4
2010

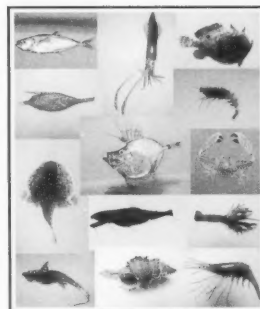
United States Department of Commerce



***Deep-Water Fishes and Invertebrates
of the U.S. Gulf of Mexico***

Marine Fisheries REVIEW

W. L. Hobart, Editor
J. A. Strader, Managing Editor



On the cover:
Deep-water fishes and invertebrates of the U.S. Gulf of Mexico. Photos by Dean Landi (formerly with NMFS Mississippi Laboratories), Brandi Noble of NMFS Mississippi Laboratories, and from the NMFS Mississippi Laboratories deep-water fishes photo archive. A species list for the cover is at the bottom of the page.

Articles

72(4), 2010

Forty Years of Winter: Cetaceans Observed
During the Southbound Migration of Gray Whales,
Eschrichtius robustus, Near Granite Canyon, Central California

Kim E. W. Sheldon and David J. Rugh 1

Fishery-independent Bottom
Trawl Surveys for Deep-water Fishes and
Invertebrates of the U.S. Gulf of Mexico, 2002–08

Mark A. Grace, Brandi Noble, Walter Ingram, Adam Pollack, and Alonzo Hamilton. 20

Soft Flesh in Sablefish, *Anoplopoma fimbria*, of Southeastern
Alaska: Relationships with Depth, Season, and Biochemistry

John F. Karinen, Harold J. Barnett, and Michelle Masuda 26

Annual Index and List of Papers

36

**U.S. DEPARTMENT
OF COMMERCE**
Gary Locke,
Secretary

**NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION**
Jane Lubchenco,
Under Secretary
for Oceans and Atmosphere

National Marine Fisheries Service
Eric Schwaab,
Assistant Administrator
for Fisheries

The *Marine Fisheries Review* (ISSN 0090-1830) is published quarterly by the Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA 98115. Annual subscriptions are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. The annual subscription price is \$21.00 domestic, \$29.40 foreign. Single copies are \$12.00 domestic, \$16.80 foreign. For new subscriptions write: New Orders, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

Although the contents of this publication have not been copyrighted and may be reprinted entirely, reference to source is appreciated.

Publication of material from sources outside the NMFS is not an endorsement, and the NMFS is not responsible for the accuracy of facts, views, or opinions of the sources. The Secretary of Commerce has determined that the publication of this periodical is necessary for the transaction of public business required by law of this Department. Use of the funds for

printing this periodical has been approved by the Director of the Office of Management and Budget.

The NMFS does not approve, recommend, or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to the NMFS, or to this publication furnished by the NMFS, in any advertising or sales promotion which would indicate or imply that the NMFS approves, recommends, or endorses any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this NMFS publication. POSTMASTER: Send address changes for subscriptions for this journal to: *Marine Fisheries Review*, c/o Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. This issue, volume 72 number 4, was printed and distributed in January 2011.

This publication is available online at
<http://spo.nwr.noaa.gov/mcontent.htm>

Cover photographs:

Left vertical row from top down: *Trachurus lathami* (rough scad), *Macroramphosus gracilis* (slender snipefish), *Halieutichthys aculeatus* (pancake batfish), *Hydrolagus alberti* (chimera). Center vertical row from top down: *Loligo pealei* (longfin inshore squid), *Zenopsis conchifera* (buckler dory), *Astronesthes similis* (family Stomiidae, dragonfishes), *Siratus beauforti* (murex). Right vertical row from top down: *Antennarius radiatus* (singlespot frogfish), *Mesopeneus tropicalis* (salmon shrimp), *Platylambrus granulatus* (bladetooth elbow crab), *Acanthaxius hirsutimanus* (family Axiidae, lobster shrimps), *Plesionika edwardsii* (soldier striped shrimp).

Forty Years of Winter: Cetaceans Observed During the Southbound Migration of Gray Whales, *Eschrichtius robustus*, Near Granite Canyon, Central California

KIM E.W. SHELDEN and DAVID J. RUGH

Introduction

The coastal waters of central California provide foraging habitat and migration corridors for a variety of temperate and warm-water cetacean taxa. In Monterey Bay and south of Carmel, deep submarine canyons penetrate the continental shelf, in some places reaching within meters of shore (Greene et al., 2002). The continental shelf narrows to within 4 km of shore south of Carmel Bay then fans out seaward to roughly 15 km off Point Sur (Fig. 1). The variety of bathymetric features provides a unique region where pelagic and coastal species intermingle.

Kim E.W. Shelden (kim.shelden@noaa.gov) and David J. Rugh are with the National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115-6349.

From 1967 to 2007, 25 censuses of southbound migrating gray whales, *Eschrichtius robustus*, were conducted in winter (primarily mid-December to mid-February) at shore-based stations just south of Carmel, Calif. (Reilly et al., 1983; Rugh et al., 2001; Shelden et al., 2004). Gray whales were the target species for the census; therefore, the study was timed to include virtually all of their southbound migration.

During these gray whale surveys, observers also recorded the presence of other cetacean species. We examined these shore-based records and observations obtained during aerial surveys in January 1988, 1993, 1994, and 1996 (Shelden and Laake, 2002), to document cetacean occurrence in winter off this portion of the central California coast. Our objective here is to describe which cetaceans are within the study area during winter,

but because the gray whale sightings have been thoroughly documented elsewhere (Shelden et al., 2004; Laake et al., 2009), this species is not included in this report.

Historically there has been little dedicated survey effort documenting cetaceans off central California during the winter months of December through February. We are aware of only two studies. The first, a pelagic fur seal study, during which cetacean sightings were recorded incidentally, occurred in 1958, 1959, and 1961 (Fiscus and Niggol, 1965), which was before the first census of gray whales in central California. The second study (Dohl et al.^{1,2}) occurred during a period (1980–83) which coincided with years when the gray whale census was not in operation. The results of those two studies are included in this review.

Methods

The study area for our review includes waters between Carmel Bay and Point Sur, Calif., extending from the coast to roughly 37 km (20 n.mi.) offshore (Fig. 1 box). Near the research sites used to count gray whales (Yankee

ABSTRACT— From December to February in most years from 1967 to 2007, observers counted gray whales, *Eschrichtius robustus*, from shore sites south of Carmel in central California. In addition to gray whales, other cetacean species were also recorded. These observations were summarized and compared among survey platforms and to ocean conditions. Eleven cetacean species were identified including eight odontocete species (killer whale, *Orcinus orca*; Pacific white-sided dolphin, *Lagenorhynchus obliquidens*; common dolphin, *Delphinus spp.*; bottlenose dolphin, *Tursiops truncatus*; northern right whale dolphin, *Lissodelphis borealis*; Risso's dolphin, *Grampus griseus*; Dall's porpoise, *Phocoenoides dalli*; and harbor porpoise, *Phocoena phocoena*) and three mysticete species (humpback

whale, *Megaptera novaeangliae*; minke whale, *Balaenoptera acutorostrata*; and blue whale, *Balaenoptera musculus*). As expected, the detection of certain species among survey platforms (shore-based census watches, 25-power "Big Eye" binocular watches, and aerial surveys) was limited by species surfacing behavior and/or bathymetric preference. Comparisons among the shore-based census efforts showed a significant difference in sightings rates from 1967–84 ($n = 14$, mean = 0.11, SD = 0.11) to 1985–2007 ($n = 11$, mean = 1.48, SD = 0.47; t -Test: $p < 0.001$, $df = 23$). The warm period observed during the 1990's may partially explain the increase in sighting rates and diversity of species observed at the census site compared to the much cooler temperatures of the 1970's.

¹Dohl, T. P., R. C. Guess, M. L. Duman, and R. C. Helm. 1983. Cetaceans of central and northern California, 1980–1983: status, abundance, and distribution. Final Rep. Minerals Manage. Serv. Contr. 14-12-0001-29090 prep. by Cent. Mar. Sci., Univ. Calif., Santa Cruz. OCS Study MMS 84-0045, 284 p.

²Dohl, T. P., M. L. Bonnell, R. C. Guess, and K. T. Briggs. 1983. Marine mammals and seabirds of central and northern California 1980–1983: synthesis of findings. Final Rep. Minerals Manage. Serv. Contr. 14-12-0001-29090 prep. by Cent. Mar. Sci., Univ. Calif., Santa Cruz. OCS Study MMS 84-0042, 248 p.

Point³ and Granite Canyon⁴), the shelf extends 4.2 km (2.25 n.mi.) offshore where it rapidly descends from 140 m to 200 m within 0.37 km (0.2 n.mi.). For all datasets, we limited the analysis of sightings to the months of December, January, and February.

Survey Datasets

Vessel Surveys 1958–61

Vessel surveys were conducted in the waters between Point Reyes (near San Francisco Bay) and Point Sur in 1958 (1 Feb.–10 Apr.), 1959 (20 Jan.–8 Apr.), and 1961 (5–15 Jan. and 16 Feb.–1 Apr.) (Fiscus and Niggol, 1965). Effort during these vessel surveys was focused from the 100 fathom (fm) curve (183 m isobath) to 185 km (100 n.mi.) offshore. Watches occurred from 0600 to 1800 h daily, and the vessel left the trackline to confirm cetacean sighting identifications only when seals were not present. Unidentified cetaceans were not recorded. Sighting and catch data presented in tables and text in Fiscus and Niggol (1965) were entered into an MSExcel⁵ spreadsheet and imported into ArcView (ESRI) to determine which fell within the boundary of the study area. Unfortunately, it was not possible for us to determine the amount of effort or where survey tracklines occurred within the study area based on the figures and descriptions provided in Fiscus and Niggol (1965).

Shore-based Census 1967–80

Systematic shore-based censuses of the southbound gray whale migration

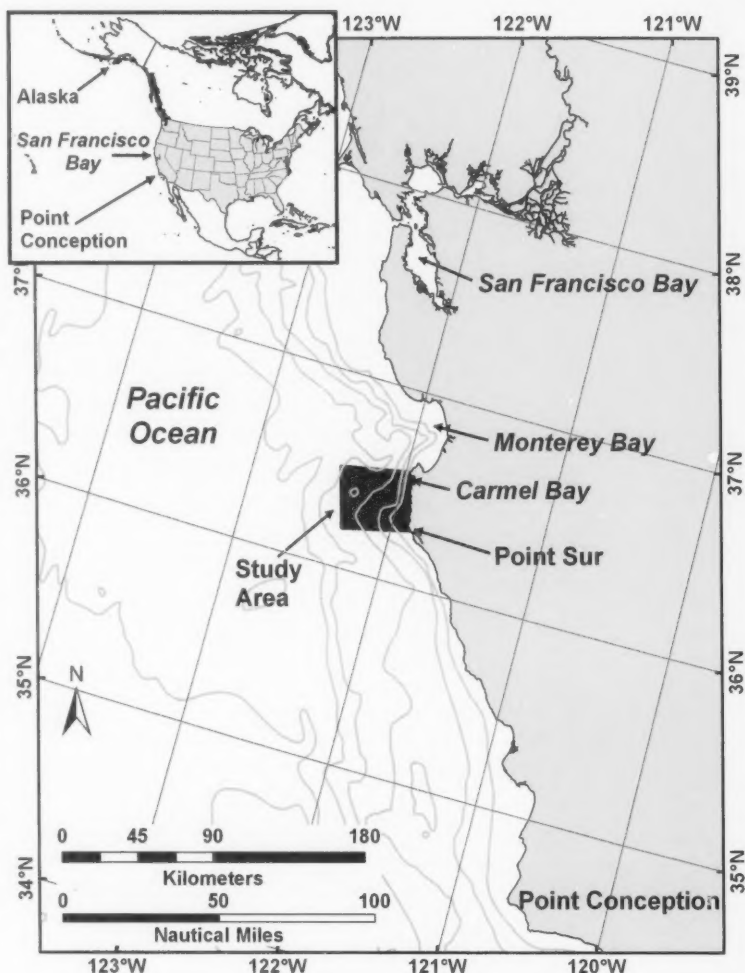


Figure 1.—Study area (box) showing place names mentioned in the text.

began in 1967 at Yankee Point (lat. 36° 29'30"N) at a site 23 m above sea level. In 1974, the census site was moved a few kilometers farther south to Granite Canyon (lat. 36° 26'41"N), to the edge of a cliff 21 m above sea level (Fig. 2). During watches, single observers rotated on 5-h shifts throughout all daylight hours (0700 to 1700 h), conducting independent searches across a 150° viewing area (Reilly et al., 1983).

Records included effort (start and stop time of systematic searches), environmental conditions (visibility, Beaufort sea state, and wind direction),

and details on sighting time and location. Sighting effort was calculated for entire watch periods as portions of a day (24 h) where average visibility was ≤ 4 (all but "poor" or "useless" viewing conditions) and Beaufort was ≤ 4 (sea state calmer than when there are moderate waves with many whitecaps; <30 km/h). Distances of the animals from shore were estimated during this period without any calibrations, so they are not considered reliable. Therefore, sighting locations could not be mapped in ArcView. Instead, these sightings are presented in tabular form. It appears that

³Yankee Point is a residential area. A house with an excellent view of the sea was made available for documenting the gray whale migration from 1967 to 1974.

⁴Granite Canyon is a research station owned by NOAA since the mid 1960's. The site has been used by California Department of Fish and Game for aquaculture research, University of California (UC) Davis for water pollution/quality studies, and a consortium including UC Santa Cruz, the Naval Postgraduate School, and Cal State University Monterey Bay to monitor ocean currents with high frequency radar (<http://www.envtox.ucdavis.edu/GraniteCanyon/SettingHistory.html>).

⁵Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.



Figure 2.—A view from sea level of the Granite Canyon research site 13 km south of Carmel in central California. This is the site from which gray whale counts have been conducted most winters 1967–2007.

the data forms and sighting protocol remained the same throughout this period. Although for the 1978–79 census, a new data form and accompanying instructions were introduced to ease key punching the hand-written data, field methodology did not change.

Aerial Surveys 1980–83

Low (60 m = 250 ft) and high (300 m = 1,000 ft) altitude aerial surveys were flown bi-weekly to document marine mammals and seabirds in the waters off central and northern California from 1980 to 1983 (Dohl et al.^{1,2}). The project was undertaken to provide data to the Pacific Outer Continental Shelf (OCS) Region of the Minerals Management Service in regard to oil and gas lease areas. East-west tracklines (92 in all) extended from shore out approximately 175 km and were broken into coastal (0–99 fm) and offshore (100–999 fm) segments. Of these, 3 of the 92 track-

lines fell within our study area. Sighting data for the south-central sector, which included waters between Point Sur (lat. 36° 20' N) and Russian River (lat. 38° 30' N), were kindly provided by Bonnell and Ford⁶, after accessing the Dohl database through OBIS-SEAMAP (Read et al.⁷). Similar to the Fiscus and Niggol (1965) dataset, sightings were imported into ArcView to determine whether any fell within the study area. Unfortunately, we could not determine how often survey tracklines were flown in the study area or if the segment flown was coastal

or offshore from the descriptions and figures provided in Dohl et al.^{1,2}

Shore-Based Census 1984–2007

After a 4-yr hiatus, gray whale census operations resumed once again in the winter of 1984–85. During this census, the same methods used during the earlier censuses were followed to allow for inter-year trend analysis (Dahlheim and Rugh⁸), and the same data form and instructions were used from 1979 to 1988. However, some adaptations have been made through the years:

- 1) Beginning with the 1985–86 census, observers rotated on three shifts covering 10 daylight hours per day (3.5 h, 3 h, and

⁶Bonnell, M. L., and R. G. Ford. 2001. Marine mammal and seabird computer database analysis system. MMS-CDAS Version 2.1. CD ROM prepared by Ecological Consulting, Portland, Oreg., for the Pacific OCS Region, Minerals Manage. Serv., Order No. 14-12-001-30183.

⁷Read, A. J., P. N. Halpin, L. B. Crowder, K. D. Hyrenbach, B. D. Best, E. Fujioka, and M. S. Coyne (Editors). 2006. OBIS-SEAMAP: mapping marine mammals, birds and turtles. World Wide Web electronic publication. Accessed 24 May 2006 [http://seamap.env.duke.edu].

⁸Dahlheim, M. E., and D. J. Rugh. 1991. A historical review of censusing gray whales. Unpubl. pap. presented to the Scientific Committee of the International Whaling Commission, SC/A90/G4, 8 p.

3.5 h) instead of only two shifts (each 5 h), and after 1993, each of the three watches was 3 h, covering 9 h per day.

- 2) In January of each year since 1985, part of the census operation included concurrent, independent watches (Rugh et al., 1990). For our analysis, cetacean sighting records from these concurrent watches (South Shed and North Shed; Fig. 3) were considered separate sightings when both observers recorded the same species at about the same time and location because the efforts were completely independent.
- 3) Since 1987, magnetic compasses and vertical reticle marks in handheld 7×50 binoculars provided data on sighting locations (Rugh et al., 1990). The focus of the sighting effort was along a line perpendicular to the coastline, at 241° magnetic.

Cetacean sighting locations (latitude and longitude) were determined using the compass bearing and reticle provided at the time of the sighting, and altitude and location (latitude and longitude) of the survey shed (NewPosLat and NewPosLon functions for Excel⁹). Distances to sightings were calculated using the RetDist7×50 function in Excel.⁹ The sightings were then plotted in ArcView and joined to nearest sounding in National Oceanic and Atmospheric Administration (NOAA) electronic nautical charts (ENC).

In most census years, any cetacean sighting other than a gray whale was treated as a comment entry in the database. Starting in December 1987, data forms were modified to include a behavioral code for gray whales associated with other species, but all other cetacean sightings were still entered as comments. In December 2001, a dedicated code was introduced on the data form to identify all other cetaceans.

All cetacean sighting (other than gray whales) were entered into an Excel spreadsheet. Unidentified cetaceans were reclassified to species only if time, location, and descriptions were similar between the paired records when only one of the observers provided a species identification. Sighting effort was limited to daily effort values in portions of a day (24 h) when the average visibility was ≤4 and Beaufort was ≤4. For data prior to 1987, the exclusion of effort was for a whole 5-h watch period at a time because changes in environmental conditions were not indicated except when sightings occurred. From 1987 onward, the data protocol included an independent code indicating when visibility or weather changed. This made it possible to exclude select portions of watch periods from the analysis.

Aerial Surveys 1988–96

Cetacean sightings were also documented during aerial surveys conducted concurrent to censuses in January 1988, 1993, 1994, and 1996 (Shelden and Laake, 2002). These aerial surveys were designed to characterize the offshore distribution of gray whales by flying tracklines perpendicular to the shore in the vicinity of the station at Granite Canyon. Earlier aerial surveys conducted in January 1973 (Sund and O'Connor, 1974) and during the 1978–79 and 1979–80 censuses (Reilly et al., 1983), also designed to characterize the gray whale migration corridor, did not report cetacean sightings other than gray whales. Therefore, only the 1988–96 surveys are used here.

Cetacean sighting locations during aerial surveys were obtained by interpolating distances from shore relative to time of sighting on the trackline (i.e. dead-reckoning) or, beginning in 1994, using global positioning system (GPS) location data (Shelden and Laake, 2002). These sighting locations were imported into ArcView. Sighting distances were compared among the three datasets: shore watch, aerial surveys, and 25× “Big Eye” binocular watches (presented in the next section) for each January when all three studies were in operation.

“Big Eye” Watches 1992–2007

Watches conducted with 25× “Big Eye” binoculars started in December 1992 at Granite Canyon (Rugh et al., 2002). Thereafter, “Big Eye” watches occurred every January, and in 2001 and 2002 the watches extended into February. Paired, independent searches for gray whales were conducted through fix-mounted “Big Eye” binoculars during 6–25 Jan. 1995 and 7–25 Jan. 1996. The “Big Eye” study was a test of an efficient method for documenting inter-year changes in the offshore distribution of the migration. Similar to the concurrent, independent shore-based census effort, the South “Big Eye” Shed and North “Big Eye” Shed (Fig. 4) were considered separate sightings when both observers recorded the same species at about the same time and location because the efforts were completely independent. As with the shore-based sightings, location and distance offshore for each “Big Eye” sighting was calculated using NewPosLon, NewPosLat, and RetDistBE⁹, respectively, and imported into ArcView.

Oceanography

Where data were available, oceanographic parameters were included with each sighting. Daily surface water temperatures were obtained from the Scripps Institution of Oceanography (SIO) Shore Station Program website¹⁰ for waters at the Granite Canyon station. Because temperatures were available only since 1971 at Granite Canyon, we explored using other sites such as Pacific Grove (near Monterey Bay) as a proxy for the earliest census years: 1967 to 1970; however, the available data were not compatible when records were kept at both sites (t -Test, $p = 0.046$, $df = 187$). A monthly surface water temperature anomaly was calculated as the difference between the average monthly temperatures for a given month and the long-term mean temperature for the calendar month from 1971 to 2007 for Granite Canyon. Anomalies were then

⁹National Marine Mammal Laboratory, Software: Excel Geometry Functions. Available at: <http://www.afsc.noaa.gov/nmml/software/excel-geo.php>

¹⁰Scripps Institution of Oceanography (SIO) Shore Station Program website. Accessed 24 April 2007 [http://shorestation.ucsd.edu/data/index_data.html].



Figure 4.—Photograph of sheds used to house two 25x “Big Eye” binoculars at Granite Canyon. The paired, independent effort through these two binoculars provided a test of sighting rates.

and 1988–89 (Hare and Mantua, 2000; Benson and Trites, 2002).

Results and Discussion

Because gray whale results are reported elsewhere (e.g. Shelden and Laake, 2002; Rugh et al., 2005; Laake et al., 2009), this species is not emphasized here. In every year of the census, gray whales were seen in great numbers (from 657 to 2,853 sightings per year; mean = 1,564 sightings, SD 514). These whales were seen on almost every day of each of the 25 censuses, sometimes with >100 sightings per day. The peak of the migration occurs in mid January, and 90% of the sightings occur in January (Rugh et al., 2001).

During whale marking cruises conducted near Yankee Point in the 1960's, it was determined that few gray whales

migrated beyond the visual range of observers on shore (Rice and Wolman, 1971). This was confirmed in January 1973, when five flights were conducted to test the width of the migration corridor (Sund and O'Connor, 1974). Results indicated that 96% of the whales passed within 4.8 km (2.6 n.mi.) of shore (94% within 1.6 km). This offshore distribution was also documented during aerial surveys near the Granite Canyon station, where fewer than 2% of the whales migrated beyond the sighting range of shore-based observers (Shelden and Laake, 2002). The census periods and sighting effort for the shore-based census are presented in Table 1.

Vessel Surveys 1958–61

According to Fiscus and Niggol (1965), “about 50 percent of the large

whales and 90 percent of the smaller cetaceans seen could be identified.” Cetacean sightings reported in the waters between Carmel Bay and Point Sur in January and February during these vessel-based surveys included gray whales (one sighting of two whales on 28 Jan. 1959) and two odontocete species: Pacific white-sided dolphins, *Lagenorhynchus obliquidens*, and Dall's porpoise, *Phocoenoides dalli* (Fig. 5). Group sizes for Pacific white-sided dolphins ranged from 4 to over 100 while Dall's porpoise group sizes ranged from 4 to 8. All odontocete sightings occurred in February.

Shore-Based Census 1967–80

During this period from 1967 to 1980 when the gray whale census was underway, there were 22 sightings of

Figure 5.—Cetaceans observed near Granite Canyon during pelagic fur seal vessel surveys Dec.–Feb. 1959 and 1961 (Fiscus and Niggol, 1965). Symbols denote gray whales (circle), Pacific white-sided dolphins (triangle), and Dall's porpoise (square).

cetaceans other than gray whales (Table 1). Of these, on average, roughly 30% were identified to species (Table 2) which included Pacific white-sided dolphins; killer whales, *Orcinus orca*; and humpback whales, *Megaptera novaeangliae*. If an observer's comment indicated he/she was not fully confident of the species identification, the sighting was not identified to species nor used in subsequent analyses (see footnotes 1 and 2 in Table 2). All useable sightings were recorded in the month of January, with the exception of a sighting of a Pacific white-sided dolphin in February 1968. Unidentified dolphin and whale sightings were also recorded most often in January (nine sightings and two sightings, respectively). We did expect a focal species bias particularly when the bulk of the gray whale migration was passing the counting stations in January. However, there is no evidence in these data that gray whale sightings significantly eclipsed records of other cetaceans.

Aerial Surveys 1980–83

Aerial surveys of the waters between Carmel Bay and Point Sur documented six odontocete species during the winters of 1980–83 (Fig. 6). The thirteen sightings included Pacific white-sided dolphins; Dall's porpoise; killer whales; Risso's dolphins, *Grampus griseus*; northern right whale dolphins, *Lissodelphis borealis*; and harbor porpoise, *Phocoena phocoena* (Table 3). A mixed-school of Risso's dolphins and northern right whale dolphins was observed on 6 Jan. 1981 (Table 3, Fig. 6). Sightings were reported in every winter month only during 1980–81; however, we do not know if flights occurred in January 1982 or February 1983 in the study area. We suspect that most of these tracklines were well offshore (100–999 fm) given the absence of gray whale sightings.

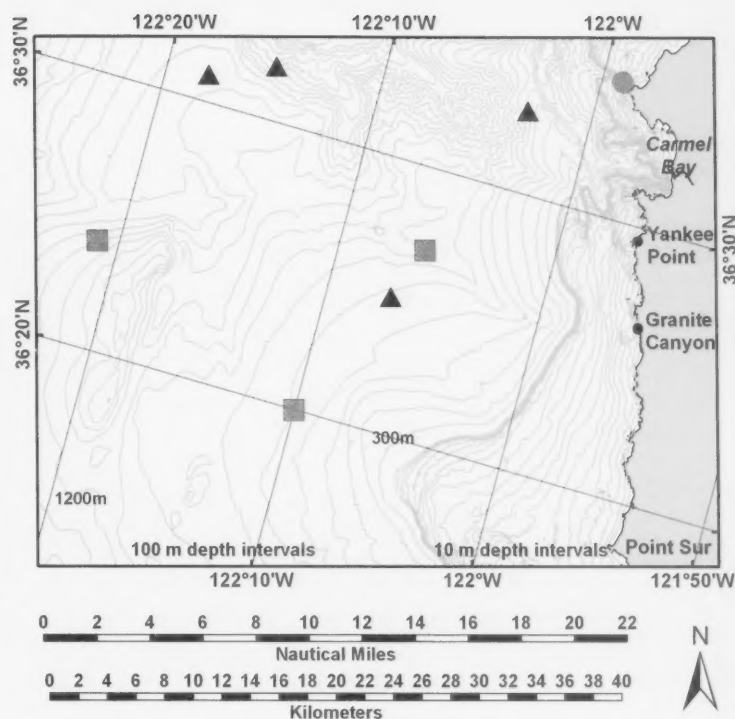


Table 1.—Number of cetacean sightings (other than gray whales and including unidentified cetaceans) reported off central California during the winter census of gray whales by observers on shore watch. Effort days (24 h) represent when average visibility was ≤ 4 and Beaufort sea state was ≤ 4 for the period December–February. The move from the Yankee Point counting site to Granite Canyon occurred after the 1973–74 census. Gaps between census years indicate when the census was not in operation.

Census sites and dates	Effort days	Sightings	Sightings per unit effort
18 Dec 1967–4 Feb 1968	12.6	2	0.16
10 Dec 1968–7 Feb 1969	15.8	0	0
8 Dec 1969–9 Feb 1970	19.4	0	0
9 Dec 1970–13 Feb 1971	24.8	3	0.12
18 Dec 1971–8 Feb 1972	14.4	0	0
16 Dec 1972–17 Feb 1973	19.4	5	0.26
14 Dec 1973–9 Feb 1974	17.7	6	0.34
10 Dec 1974–7 Feb 1975	19.8	1	0.05
10 Dec 1975–4 Feb 1976	12.2	1	0.08
10 Dec 1976–7 Feb 1977	21.6	2	0.09
10 Dec 1977–5 Feb 1978	8.1	0	0
10 Dec 1978–9 Feb 1979	21.7	1	0.05
10 Dec 1979–7 Feb 1980	15.7	1	0.06
28 Dec 1984–7 Feb 1985	11.2	3	0.27
10 Dec 1985–7 Feb 1986	26.7	25	0.94
10 Dec 1987–7 Feb 1988	44.0	42	0.95
10 Dec 1992–7 Feb 1993	23.6	42	1.78
10 Dec 1993–17 Feb 1994	30.0	56	1.87
6–26 Jan 1995	3.4	4	1.18
10 Dec 1995–23 Feb 1996	19.9	28	1.40
9–23 Jan 1997	6.9	9	1.30
13 Dec 1997–24 Feb 1998	22.3	31	1.39
13 Dec 2000–5 Mar 2001	31.2	68	2.18
12 Dec 2001–5 Mar 2002	25.0	34	1.36
12 Dec 2006–22 Feb 2007	23.1	43	1.87
Total	490.6	407	

Shore-Based Census 1984–2007

Non gray whale cetacean sighting rates increased significantly after 1984 (Table 1). Although there were some minor methodological changes made during the 1985–86 census, they do not account for such a dramatic change in sighting rates. The data forms and instructions used in 1985–86 were first used during the 1979–80 census. The only changes to survey methods were including paired, independent effort during January, reducing the length of watch periods, and providing vertical and horizontal data on each sighting. These changes are not thought to have raised or lowered the probability of recording sightings.

After comparing observers and sighting records from the earliest years of the census, we determined that observers

were recording any cetacean they saw. It was just that cetaceans other than gray whales “were few and far between” in those early years of the census (Rice¹²). Comparisons among the primary sighting efforts show a significant difference in sightings rates from 1967–84 ($n = 14$, mean = 0.11, SD = 0.11) to 1985–2007 ($n = 11$, mean = 1.48, SD = 0.47; t-Test: $p < 0.001$, $df = 23$). Within-season comparisons showed good agreement, in that sighting rates between the paired sheds (Table 4) were not significantly different (t-Test: $p = 0.58$, $df = 18$).

Eleven species were identified during the latter half of the census years, since 1985 (Table 5), including seven species reported during the earlier studies:

¹² Rice, Dale, Gray Whale Census Project Leader 1967–1980. National Marine Mammal Laboratory, NOAA, NMFS, Seattle, Wash. Personal commun. 23 April 2007.

Pacific white-sided dolphins, Dall’s porpoise, killer whales, Risso’s dolphins, northern right whale dolphins, harbor porpoise, and humpback whales. A little over half (on average 57%) of all odontocete sightings reported by shore-based observers were identified to species compared to 71% of mysticete sightings (Table 5). Dall’s porpoise, harbor porpoise, and northern right whale dolphins were rarely observed from shore (Table 5). These species are found year-round off the central California coast (Leatherwood et al., 1982; Forney, 1997; Chivers et al., 2002). Dall’s porpoise can be very visible when “rooster tailing,” but group sizes were small. Small group sizes and low surfacing profile also made detection of northern right whale dolphins and harbor porpoise difficult, and northern right whale dolphins were only observed in mixed-species groups.

Three species (Risso’s dolphins; common dolphins, *Delphinus* spp.; and bottlenose dolphins, *Tursiops truncatus*) were first recorded by the census teams during the 1980’s. Two separate species of common dolphins occur off central California (Heyning and Perrin, 1994; Benson et al., 2002): long-beaked, *Delphinus capensis*, and short-beaked, *D. delphis*. However, observers did not report common dolphins to the species level. Bottlenose dolphins were also seen north and south of the gray whale census study site in December 1984, January 1985, and December 1986, during periods when the census was not in operation (Wells et al., 1990). Our first sighting of bottlenose dolphins (a group of 15 seen on 28 December 1987) occurred only one day before the sightings reported by Alan Baldrige (Wells et al., 1990). The coastal population of bottlenose dolphins is usually found within 1 km (0.5 n.mi.) of shore (Hansen, 1990; Hanson and Defran, 1993) with a preference for depths of 20 m or less (Leatherwood and Reeves, 1982) (Fig. 7, Box A). All three of these species have been observed during almost every census since the 1982–83 El Niño (Table 5). These species are often observed in large surface-active schools, increasing their likelihood of detection.

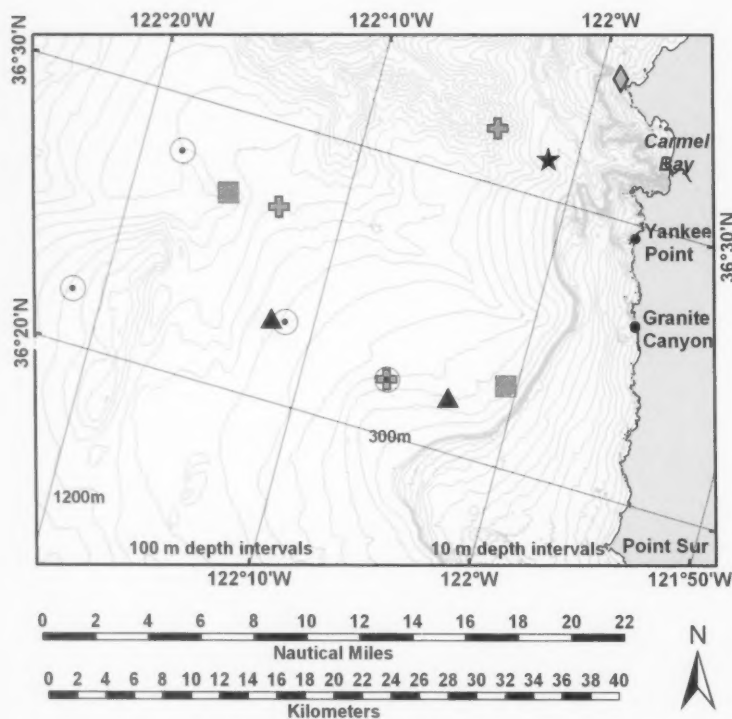


Figure 6.—Cetaceans in the Granite Canyon study area observed during aerial surveys Dec.–Feb. 1980–83 (Dohl et al.^{1,2}). Symbols denote Pacific white-sided dolphins (triangle), Dall’s porpoise (square), northern right whale dolphins (circle), killer whales (star), Risso’s dolphins (cross), and harbor porpoise (diamond).

Two whale sightings were tentatively identified as minke whales, *Balaenoptera acutorostrata*, during the 1972–73 census (Table 2; footnote 2); however, it was not until the 1985–86 season that 12 confirmed sightings were reported (Table 5).

Blue whales, *Balaenoptera musculus*, were seen only during the 1992–93 census (Table 5). The sighting of two whales traveling south occurred in December. Blue whales as well as humpback whales migrate to waters south of California in the winter and do not return until spring (Calambokidis and Barlow, 2004; Croll et al., 2005; Keiper et al., 2005; Dohl et al.^{1,2}).

Overall, shore-based observers were limited by their ability to detect and identify species at great distances. Shelden and Laake (2002) noted that shore-based observers were able to see some gray whales as far away as the horizon (16 km, as calculated with reticles in 7×50 binoculars) under ideal conditions, but most searching is conducted without the aid of binoculars, so generally whale surfacings occurring at distances of 9 km or greater may go undetected. For other cetaceans observed during the census, all sightings identified to species were within 7.4 km (4 n.mi.) of shore (Fig. 7).

Aerial Surveys 1988–96

In the 4 years aerial surveys were conducted concurrent with shore-based census operations, 7 of the 11 species were reported (Table 6). On average, 75% of odontocete sightings and 100% of baleen whales were identified to species. Most sightings occurred beyond the continental shelf (Fig. 8). Risso's dolphins comprised over half of the total sightings. Risso's and common dolphins were the only species reported during all aerial survey years (Table 6). Detections were likely biased toward larger schools of surface-active species given the survey altitude of 305 m (1,000 ft) and the intense focus on documenting all gray whales within the study area.

"Big Eye" Watches 1992–2007

The "Big Eye" study provided yet another perspective to documenting cetaceans during the eight years this

Table 2.—Cetaceans reported during the southbound gray whale census, 1967–80 (for the period December–February). For identified species, number of sightings is followed by group size in parenthesis. The move from the Yankee Point counting site to Granite Canyon is shown by the gap dividing the two time periods.

Census	Pacific white-sided dolphins	Killer whales	Humpback whales	Unidentified dolphins	Unidentified whales
1967–68	1 (3-4)			1	
1968–69					
1969–70					
1970–71		1 (4-5)		2	
1971–72					
1972–73				3 ¹	2 ²
1973–74				5	1
1974–75	1 (4-5)				
1975–76				1	
1976–77		1 (2)		1	
1977–78					
1978–79			1 (2)		
1979–80				1	
Total sightings	2	2	1	14	3

¹ Observer comment on one sighting stated "noticed successive pods of porpoises coming toward site, they were probably Pacific striped" (i.e. *Lagenorhynchus obliquidens*).

² Observer comment on one sighting stated "following shoreline, small whale with low shapeless blow visible only in south quadrant with sun shining through it, small slightly hooked dorsal fin, looked more like a minke whale than any beaked whale shown in the 'Guide...'"

Table 3.—Cetaceans reported during winter aerial surveys, 1980–83 (Dohl et al.^{1,2}). Number of sightings is followed by parenthesis containing group size(s). Number of surveys where cetaceans were observed is shown in parenthesis for each winter (total effort is not known).

Years	Pacific white-sided dolphins	Killer whales	Risso's dolphins	Northern right whale dolphins	Dall's porpoise	Harbor porpoise
1980–81 (5 surveys)	1 (10)	1 (4)	2 (12, 150 ¹)	4 (6, 18, 400, 2000)	1 (1)	
1981–82 (2 surveys)					1 (8)	1 (1)
1982–83 (2 surveys)	1 (10)		1 (21)			
Total sightings	2	1	3	4	2	1

¹ This group of Risso's dolphins (about 150 animals) was in a mixed-school with about 400 northern right whale dolphins (noted as a separate sighting in this table, see also Fig. 6).

Table 4.—Number of cetacean sightings (other than gray whales and including unidentified cetaceans) reported off central California during the winter census of gray whales by observers on shore watch in years when a secondary effort occurred. Effort days (24 h) represent when average visibility was ≤ 4 and Beaufort sea state was ≤ 4 for the time period mid-December to mid-February.

Census	Primary watch			Secondary watch		
	Effort days	Sightings	Sightings per unit effort	Effort days	Sightings	Sightings per unit effort
1985–86	22.2	21	0.95	4.6	4	0.87
1987–88	22.2	18	0.81	21.8	24	1.10
1992–93	18.4	33	1.79	5.2	9	1.72
1993–94	22.9	42	1.84	7.1	14	1.96
1995–96	17.6	20	1.14	2.3	8	3.46
Jan. 1997	3.5	6	1.71	3.4	3	0.88
1997–98	16.7	22	1.32	5.6	9	1.61
2000–01	21.6	52	2.41	9.6	16	1.66
2001–02	19.7	28	1.42	5.3	6	1.13
2006–07	19.4	34	1.76	3.7	9	2.43
Total	184.1	276	Mean = 1.51 SD = 0.48	68.8	102	Mean = 1.68 SD = 0.80

project occurred concurrent with the census. All species with the exception of blue and humpback whales recorded by census observers were also recorded by "Big Eye" observers (Table 7). Similar to aerial survey results, Risso's and

common dolphins were the only species reported during all survey years (Table 7). The fixed aspect of the binoculars and narrow field of view limited sightings to a band along the 241° magnetic bearing (Fig. 9), with the exception of a

Table 5.—Cetaceans reported during the southbound gray whale census, 1984–2007 (for the time period mid-December to mid-February). Number of sightings is followed by parenthesis containing the number of sightings for which an offshore position (latitude, longitude) could be calculated from the reticle and bearing provided in the comment string. Group sizes (where recorded) for each sighting are reported in Appendix 1 (available from authors).

Species	1984–85	1985–86	1987–88	1992–93	1993–94	Jan. 1995	1995–96	Jan. 1997	1997–98	2000–01	2001–02	2006–07	Total
Minke whale		12	4 (3)	1 (1)	1 (1)		2 (2)						20 (7)
Blue whale				1 (1)									1 (1)
Common dolphin	1		6 (5)	16 (13)	10 (10)	1 (1)	2 (1)	2 (2)	7 (7)	9 (9)	1 (1)	3 (3)	58 (52)
Risso's dolphin		5		12 (11)	9 (7)			3 (3)		10 (10)	3 (3)	14 (13)	56 (47)
Northern right whale dolphin				1 (1)									1 (1)
Pacific white-sided dolphin				1 (1)	2 (2)			1 (1)		1 (1)		1 (1)	6 (6)
Humpback whale				1 (1)	1 (1)		2 (1)			3 (3)		2 (2)	9 (8)
Killer whale		4			2 (2)	1 (1)	2 (2)	1 (1)	5 (5)	3 (2)			18 (13)
Dall's porpoise						1 (1)				1 (1)			2 (2)
Harbor porpoise				1 (1)						1 (1)			2 (2)
Bottlenose dolphin			2 (2)		2 (2)		3 (3)	1 (1)	3 (3)		11 (11)	8 (8)	30 (30)
Unidentified dolphins	2	4	28 (18)	5 (5)	28 (23)	1	17 (16)	1 (1)	16 (13)	38 (32)	13 (13)	15 (12)	168 (133)
Unidentified whales			2 (1)	3 (3)	1 (1)					2 (2)	6 (6)		14 (13)
Total	3	25	42 (29)	42 (38)	56 (49)	4 (3)	28 (25)	9 (9)	31 (28)	68 (61)	34 (34)	43 (39)	385 (315)

few sightings made in December 1992 when binoculars were not yet locked in place horizontally (Fig. 9, main map and box A inset). Although cetaceans

were identified to species as far as the horizon (about 17 km (9 n.mi.)), most identifications occurred within 5.5 km of shore (Fig. 9, boxes B and C; Table

8). Sighting effort beyond 6.3 km was 36% to 53% lower than in sighting bins closer to shore due to visibility (Table 8). The field of view in these binoculars also excluded any sightings that may have occurred within 0.6 km of shore.

Survey Platform Comparison

During periods when all three survey platforms were operating concurrently (January 1993, 1994, 1996), we compiled sightings into distance bins and included only those species reported by at least two of the survey platforms (Fig. 10). The three plots show some of the limitations of each dataset given the diversity of species present in the study area and factors that influence observer detection rates such as habitat and behaviors. Five species were observed from all platforms: minke whales, common dolphins, Risso's dolphins,

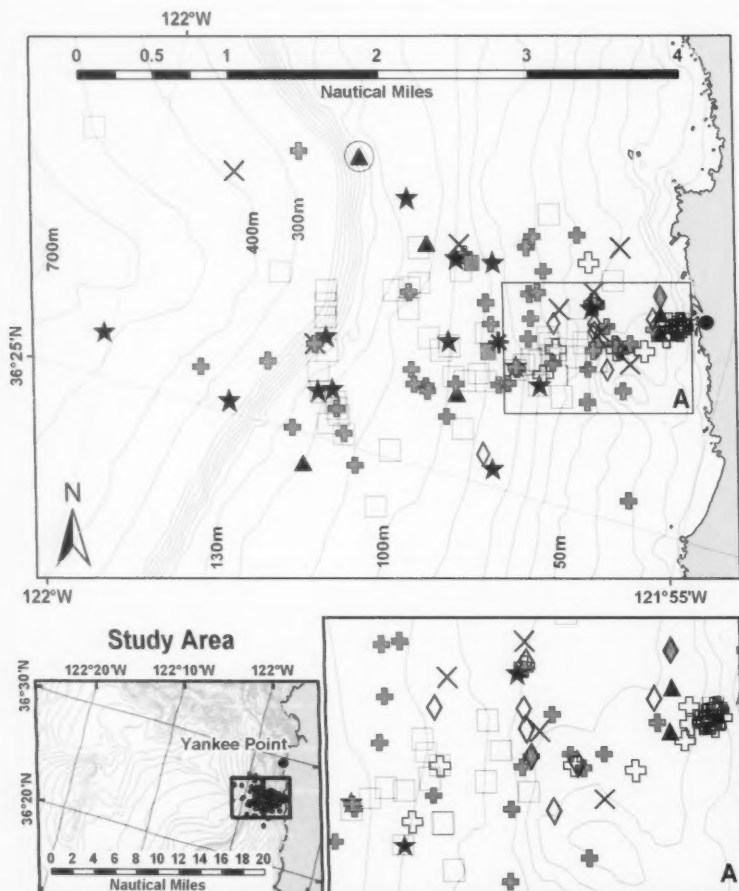


Figure 7.—Cetaceans seen within about 7 km (4 n.mi.) of the Granite Canyon research station during the southbound migration of gray whales mid-December to mid-February 1987–2007. The overview map shows the 7 km sighting range from Granite Canyon. Symbols denote Pacific white-sided dolphins (black triangle), Dall's porpoise (gray square), northern right whale dolphins (open circle), killer whales (black star), Risso's dolphins (gray cross), harbor porpoise (gray diamond), minke whale (open diamond), blue whale (black asterisk), humpback whale (x symbol), common dolphins (open square), and bottlenose dolphins (open cross). Box A zooms in on the cluster of sightings closest to the survey station (the tight cluster nearest shore includes 4 sightings of common dolphins and 21 sightings of bottlenose dolphins).

Pacific white-sided dolphins, and killer whales.

All sightings of minke whales were of lone animals, with the shore-based platform detections occurring closest to shore (Fig. 10a, b) and the aerial observation occurring at the offshore end of a trackline (Fig. 10c). Minke whales have been observed in the study area year-round and seem to have established home ranges (Dorsey et al., 1990), but they tend to be very cryptic, travel alone, and rarely display active surfacing behaviors (Leatherwood et al., 1982; Stern, 1992). In contrast, the odontocetes reported by all three platforms were rarely alone.

The number and distribution of common dolphin sightings were similar among the survey platforms (Fig. 10), with the exception of two aerial sightings that occurred beyond 18 km offshore (Fig. 10c).

Aerial sightings of Risso's dolphins were distributed across the range of distance bins with the majority of sightings occurring beyond the visual range of census observers (Fig. 10c), which may be indicative of a pelagic distribution (Leatherwood et al., 1980). This preference for deep water could explain why Risso's dolphins were not reported by census observers in 1988 (Table 5), although aerial surveys documented 24 sightings in the study area (Table 6). When aerial surveys extended north to Monterey Bay (1988 and 1993), Risso's dolphins were also observed primarily over submarine canyons.

Pacific white-sided dolphins were reported in most of the distance bins, but sightings appeared to peak around 5–7 km from shore (Fig. 10b, c), once again near the outer limits for census observers to successfully identify this species. In 1996, the largest number of sightings occurred during aerial (Table 6) and "Big Eye" (Table 7) studies, yet Pacific white-sided dolphins were not reported by census observers that winter (Table 5).

For killer whales, group sizes (when noted) ranged from one to five animals and often included at least one adult male. All sightings (aerial and Big Eye) were within the visual range of the

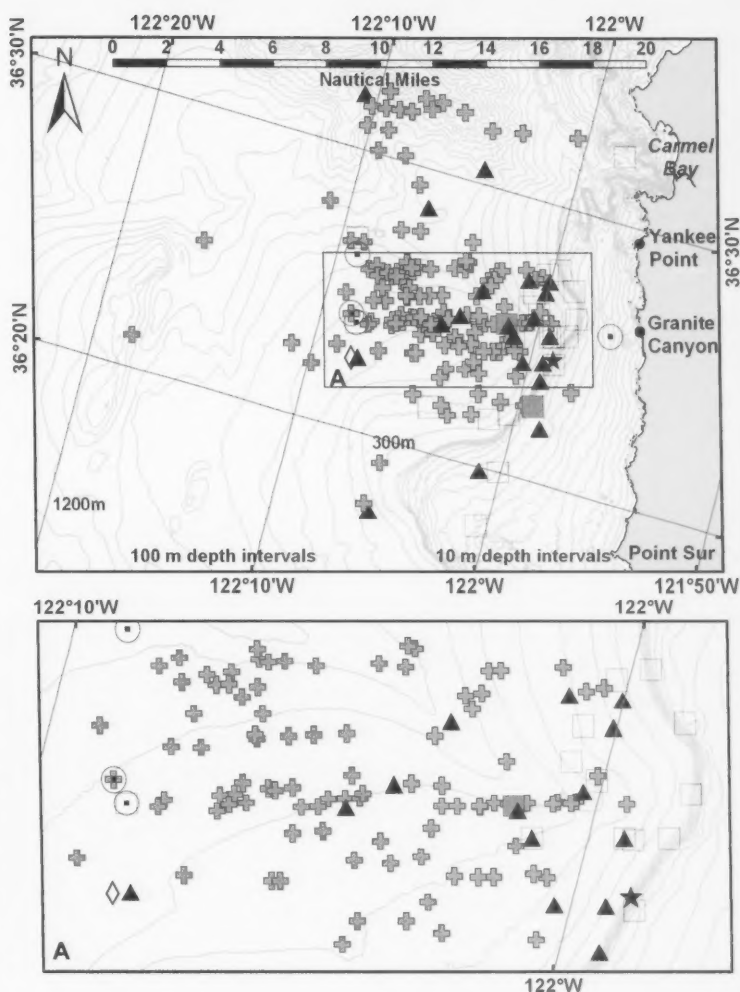


Figure 8.—Cetaceans in the study area observed during aerial surveys of the south-bound migration of gray whales, Jan. 1988–96. Symbols denote Pacific white-sided dolphins (black triangle), Dall's porpoise (gray square), northern right whale dolphins (open circle), killer whales (black star), Risso's dolphins (gray cross), minke whale (open diamond), and common dolphins (open square). Box A zooms in on the cluster of sightings near the Granite Canyon survey station.

census observers (Fig. 10). Killer whales are also observed year-round in central California waters (Black et al., 1997; Dohl et al.^{1,2}). There are three ecotypes, each of which has been observed in the Monterey area during winter (Black et al., 1997; Black¹³). "Resident" killer whales feed exclusively on fish and seem to be rare visitors to California. Photographs of killer whales seen in

Monterey Bay on 29 Jan. 2000 and 13 Mar. 2003 were matched to whales usually seen in Washington State waters (Black¹³). "Offshore" killer whales occur in groups of 40 to 100 and are

¹³Black, N. A. 2000. Killer whales from Puget Sound observed in Monterey Bay. Monterey Bay Whale Watch website. Accessed 15 Aug. 2006. <http://www.montereybaywhalewatch.com/Features/feat0002.htm>

occasionally seen in the Monterey area in winter. "Transient" killer whales are the most frequently observed ecotype in the Monterey area (Black et al.,

1997; Black¹³). This ecotype travels in small groups and preys on other marine mammals. Killer whale presence during census years was correlated to the sea-

sonal presence of gray whale calves (Shelden et al., 1995), implying that the killer whales observed in this study might be transient-type animals. This assumption is also supported by the small group sizes observed.

Northern right whale dolphins were recorded by "Big Eye" and aerial observers but very rarely by census observers (the lone sighting reported by census observers occurred in December 1992; see Table 5). As mentioned earlier, all sightings of this species occurred in close proximity to or within mixed-species schools of dolphins which, along with their low surfacing profile and lack of dorsal fin, increases the likelihood of under-reporting this species.

Harbor porpoise and bottlenose dolphins were never reported by aerial observers. Most bottlenose dolphin sightings made by census observers occurred in the surf zone (Fig. 10a), an area where whitecaps would make aerial detections difficult and, in most cases, too close to shore to be seen in the "Big Eye" binoculars. Harbor porpoise were in the study area year-round and seem to have established home ranges (Chivers et al., 2002), but they also present a low profile when surfacing and usually travel alone (Leatherwood et al., 1982), leading to under-reporting. Aerial surveys conducted by the Southwest Fisheries Science Center have been used to estimate abundance of these species along the central California coast since the mid-1980's (Forney et al., 1991; Forney et al., 1995; Forney, 1997, 1999; Carretta et al., 2009). However, these surveys were flown at about 213 m (650 to 700 ft; much lower than the gray whale aerial surveys at 305 m (1,000 ft)) "because of the small body size of harbor porpoise"¹⁴ and in the earlier years only found the offshore, not coastal, population of bottlenose dolphins (Forney et al., 1995; Forney, 1997). Forney et al. (1995:25) concluded that "[p]recise estimates of abundance for harbor porpoise and inshore bottlenose dolphins will require

Table 6.—Cetacean sightings reported during aerial surveys of the southbound gray whale migration, January 1988–96. Effort hours in conditions where visibility was fair or better include tracklines (10–20 n.mi.; Shelden and Laake, 2002), pod size estimation experiments, and photogrammetric surveys. Group sizes (where recorded) for each sighting are reported in Appendix 2 (available from authors).

Species	1988 (25.5 h)	1993 (16.1 h)	1994 (31.0 h)	1996 (15.2 h)	Total
Minke whale				1	1
Blue whale					0
Common dolphin	8 ¹	1	5	9	23
Risso's dolphin	24 ¹	16	83	12	135
Northern right whale dolphin			2	2	4
Pacific white-sided dolphin	6			14	20
Humpback whale					0
Killer whale				1	1
Dall's porpoise	1		2		3
Harbor porpoise					0
Bottlenose dolphin					0
Unidentified dolphins	20 ¹	8	17	9	54
Unidentified whales					0
Total	59	25	109	48	241
Sightings per unit effort	2.31	1.55	3.52	3.16	

¹ Total includes sightings made during photographic surveys where latitude and longitude data were not collected: three sightings of common dolphins, two sightings of Risso's dolphins, and two sightings of unidentified dolphins.

Table 7.—Cetaceans reported during 25x "Big Eye" binocular watches of the southbound gray whale migration, 1992–2007. Group sizes (where recorded) for each sighting are reported in Appendix 3 (available from authors). Effort hours include visibility 4 (fair) or better for all reticle fields.

Species	1993 1/3–31 (23.0 h)	1994 1/10–31 (39.8 h)	1995 1/7–25 (146.6 h ¹)	1996 1/7–25 (252.6 h ¹)	1998 1/7–26 (107.6 h ¹)	2000–01 12/29–1/23 (54.6 h ¹)	2002 1/3–2/4 (53.1 h ¹)	2007 1/8–31 (19.6 h ¹)	Total
Minke whale			2	2	1		1		6
Blue whale									0
Common dolphin	8	1	19	15	2	7	2	1	55
Risso's dolphin	7	2	4	7	3	14	3	2	42
Northern right whale dolphin				5					5
Pacific white-sided dolphin				13	3	1			17
Humpback whale									0
Killer whale		1	4		10	2	1		18
Dall's porpoise			4			1			5
Harbor porpoise			3	3	2	1			9
Bottlenose dolphin		1					3		4
Unidentified dolphins	4	3	21 ²	55 ²	17 ²	13	4	3 ²	120
Unidentified whales			2			1			3
Total	19	8	59	100	38	40	14	6	284

¹ From 1995 onward, visibility codes were applied to reticle bins for the horizon (0.0) to 1.0 reticles (R), 1.1–2.0 R, 2.1–3.0 R, 3.1–4.0 R, and 4.1–20.0+ R. The greatest amount of effort occurred in the 4.1–20.0+ R bin (shown here). Effort per reticle bin is further defined in Table 8.

² Total includes one sighting where reticle was not provided.

Table 8.—Effort hours where visibility was 4 (fair) or better for all reticle fields, and number of cetacean sightings identified to species (with unidentified sightings in parenthesis) during 25x "Big Eye" binocular watches of the southbound gray whale migration. Paired, independent searches occurred in January 1995 and 1996 (shown as South and North shed). Note: 0.0 = horizon (at 9.1 n.mi. (16.8 km) offshore); 0.35 n.mi. (0.65 km) is the closest to shore a sighting could be detected in the field of view of the binoculars (about 24 reticles).

Reticle bins	1995		1996		1998	2000–01	2002	2007
	South	North	South	North				
0.0–1.0	30.9, 0(2)	29.2, 0(3)	48.7, 5(14)	46.2, 7(8)	60.9, 4(6)	22.5, 0(6)	24.6, 1(2)	14.2, 0(0)
1.1–2.0	47.4, 9(4)	47.1, 7(1)	83.9, 12(15)	89.2, 6(8)	78.7, 7(7)	43.5, 4(3)	40.3, 2(0)	17.0, 2(0)
2.1–3.0	65.2, 3(1)	65.2, 3(2)	112.0, 3(3)	114.6, 5(2)	98.9, 1(2)	52.4, 4(2)	51.2, 1(2)	18.7, 1(0)
3.1–4.0	71.9, 4(2)	71.3, 3(0)	119.8, 2(0)	125.1, 0(0)	105.5, 2(0)	53.8, 9(2)	52.8, 3(0)	18.9, 0(0)
4.1–20.0+	73.6, 1(2)	73.0, 6(5)	124.0, 2(3)	128.6, 3(1)	107.6, 7(1)	54.6, 9(1)	53.1, 3(0)	19.6, 0(2)

¹⁴ Southwest Fisheries Science Center (SWFSC). Harbor Porpoise Aerial Survey website. Accessed 17 Sept. 2010. <http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuID=148>

dedicated aerial surveys designed for those species."

Overall, shore-based observers were limited by their ability to identify species at great distances, and "Big Eye" observers were unable to survey within 0.6 km of shore. Aerial surveys were conducted at 305 m (1,000 ft) altitude, ideal for viewing large whales and large schools of dolphins but not for smaller cetaceans that tend to travel alone or in small groups.

Oceanography

The increased diversity of cetacean species observed after 1980 off central California (Dohl et al.^{1,2}; our study) may, in part, be because of oceanographic warming observed from the 1980's through the 1990's (Lluch-Belda et al., 2001, 2003, 2005). This was evident in the number of warm months that occurred during gray whale census operations after 1989 (Table 9). A similar increase in diversity of odontocete species in Monterey Bay was observed following the onset of the 1997–98 El Niño (Benson et al., 2002).

Northward dispersal of fauna during warm periods has been described for a number of southern California species (Lluch-Belda et al., 2003, 2005). These faunal assemblages include prey important to cetaceans such as sardines, *Sardinops sagax*; anchovy, *Engraulis mordax*; squid, and zooplankton. Genetic analysis of population structure of the market squid, *Loligo opalescens*, a common prey species of many of the odontocetes described here, suggests a north and south migration within shelf waters (Reichow and Smith, 2001) as well as inshore and offshore movements during the spawning season (Spratt, 1979). Warm waters play a key role in the spawning cycles and locations used by many of these prey species (Hernandez-Vazquez, 1994; Lluch-Belda et al., 2001), and the range of some of these species has extended north to Alaska during strong El Niño years (Wing and Mercer, 1990; Wing et al., 2000).

The 1977 and 1989 Pacific regime shifts also affected abundance, recruitment, and biomass of a number of

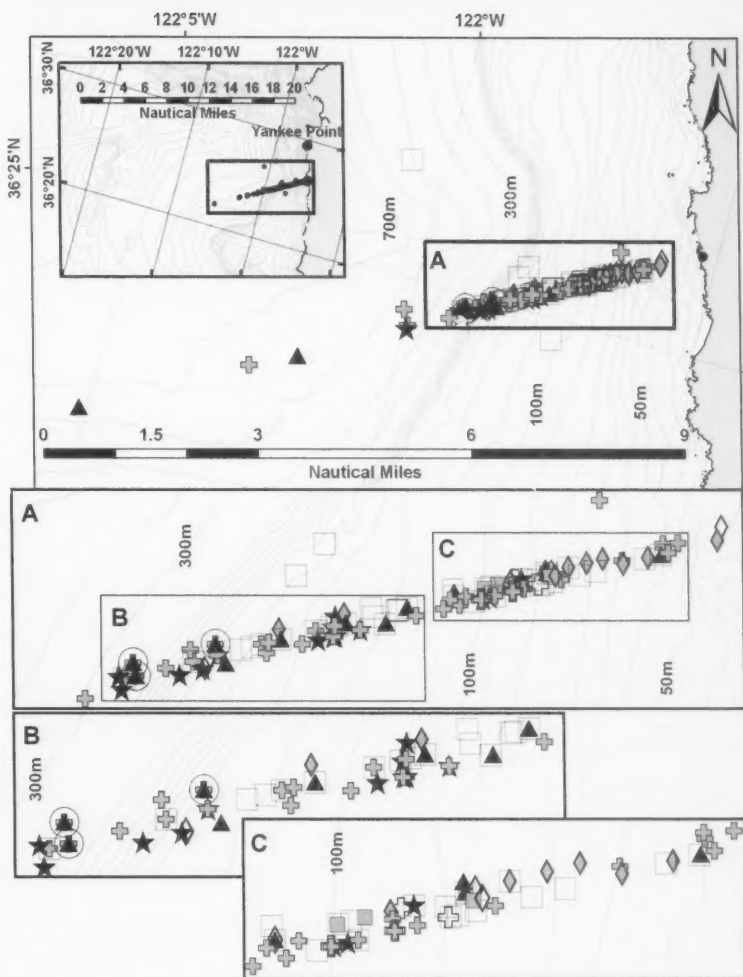


Figure 9.—Cetaceans in the Granite Canyon study area observed through "Big Eye" (25×) binoculars (see also Fig. 4) during systematic watches of the southbound migration of gray whales, 1992–2007. Symbols denote Pacific white-sided dolphins (black triangle), Dall's porpoise (gray square), northern right whale dolphins (open circle), killer whales (black star), Risso's dolphins (gray cross), harbor porpoise (gray diamond), minke whale (open diamond), common dolphins (open square), and bottlenose dolphins (open cross). Boxes A, B, and C zoom in on the cluster of sightings closer to shore.

cetacean prey species. Small pelagic fishes appeared to benefit from warmer temperatures while declines were noted in a number of larger pelagic fishes (e.g. Pacific salmonids) and groundfish (see review in Benson and Trites, 2002). In particular, after the 1989 regime shift, production improved off California for Pacific hake, *Merluccius productus*;

herring, *Clupea pallasii*; and sardines (Benson and Trites, 2002). The distribution of hake and sardines northward was also observed after 1989 (Benson and Trites, 2002). It is possible that sighting rates of common, Risso's, Pacific white-sided, and bottlenose dolphins were also driven by these shifts in prey availability (e.g. Keiper et al., 2005).

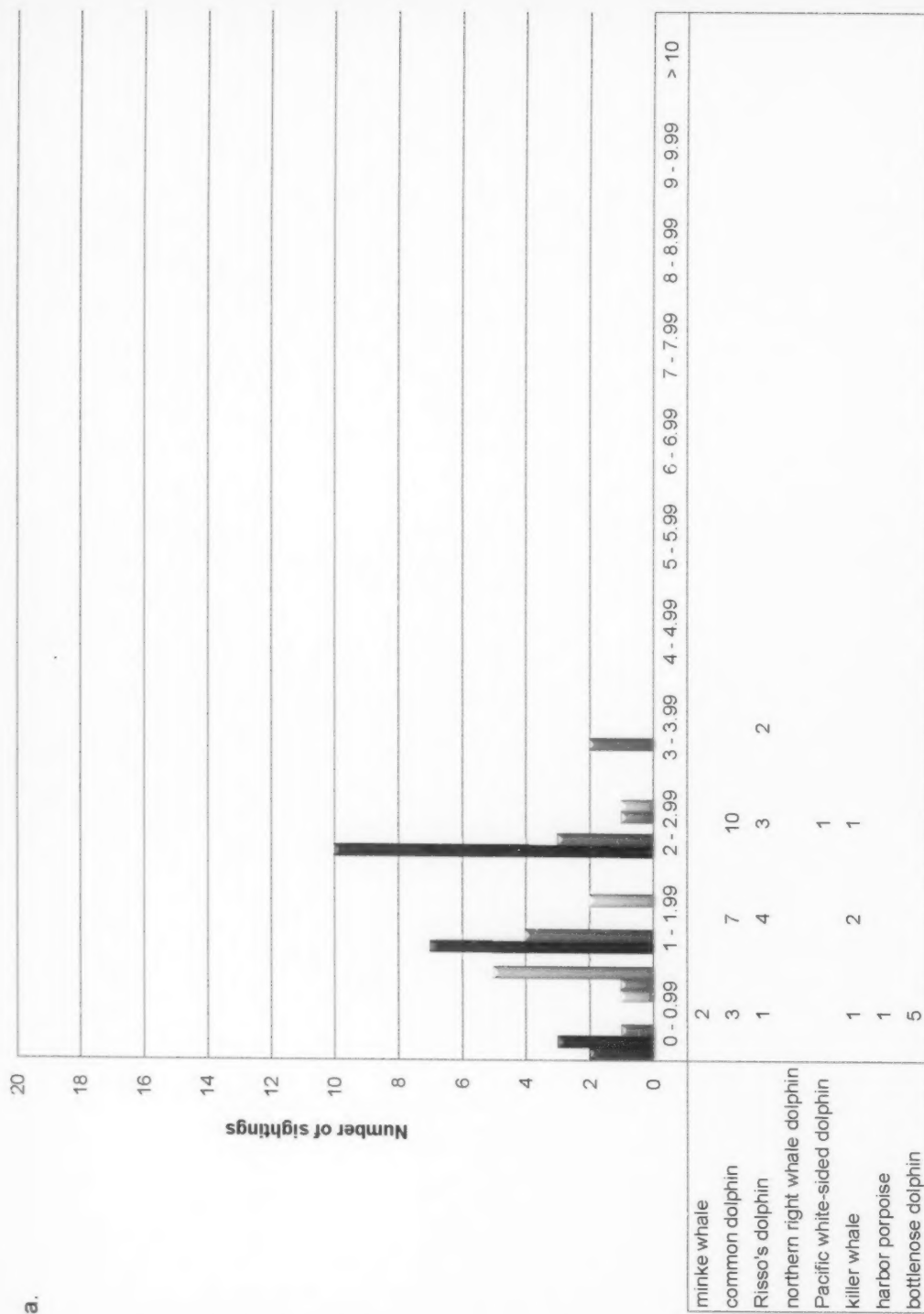
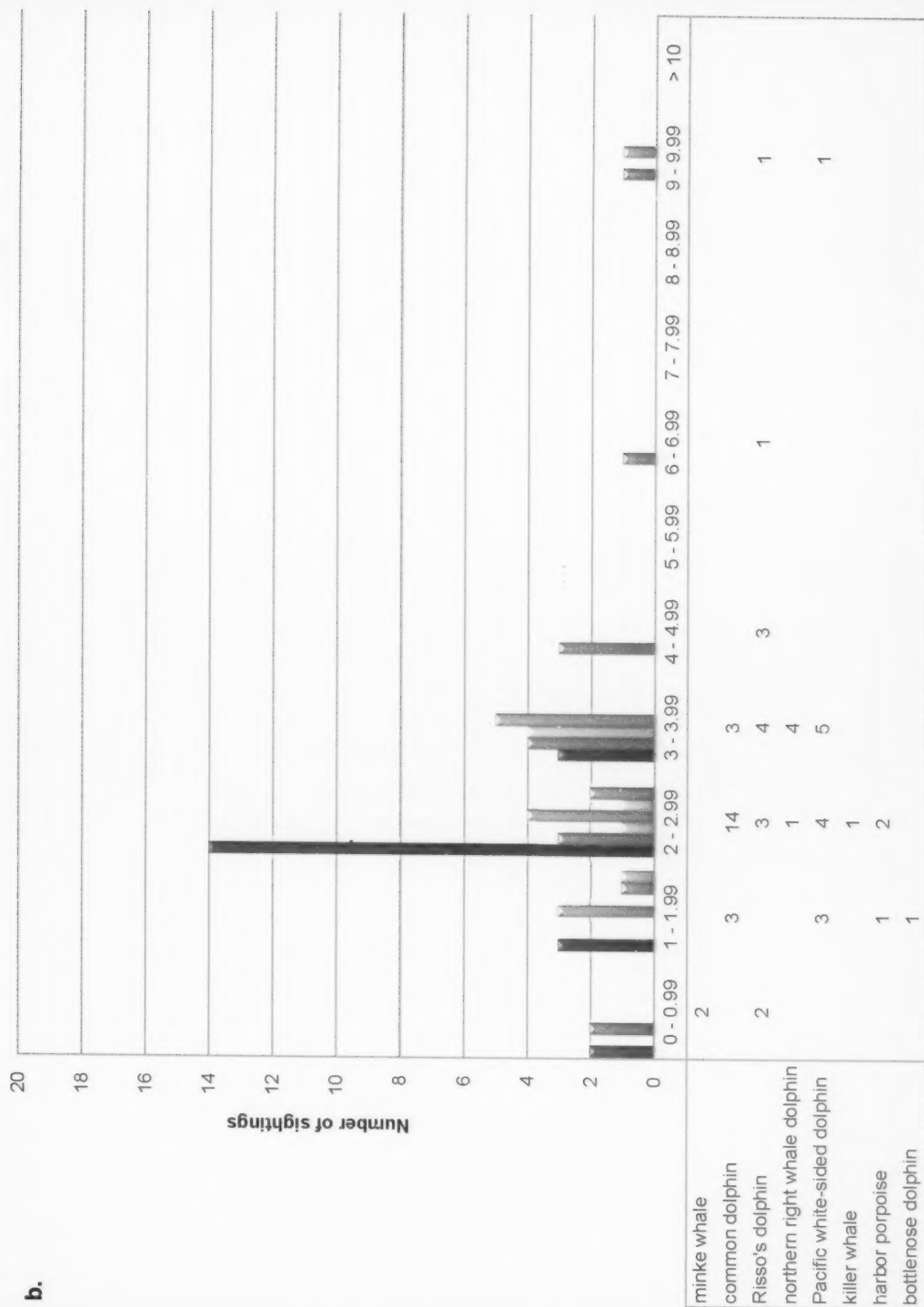
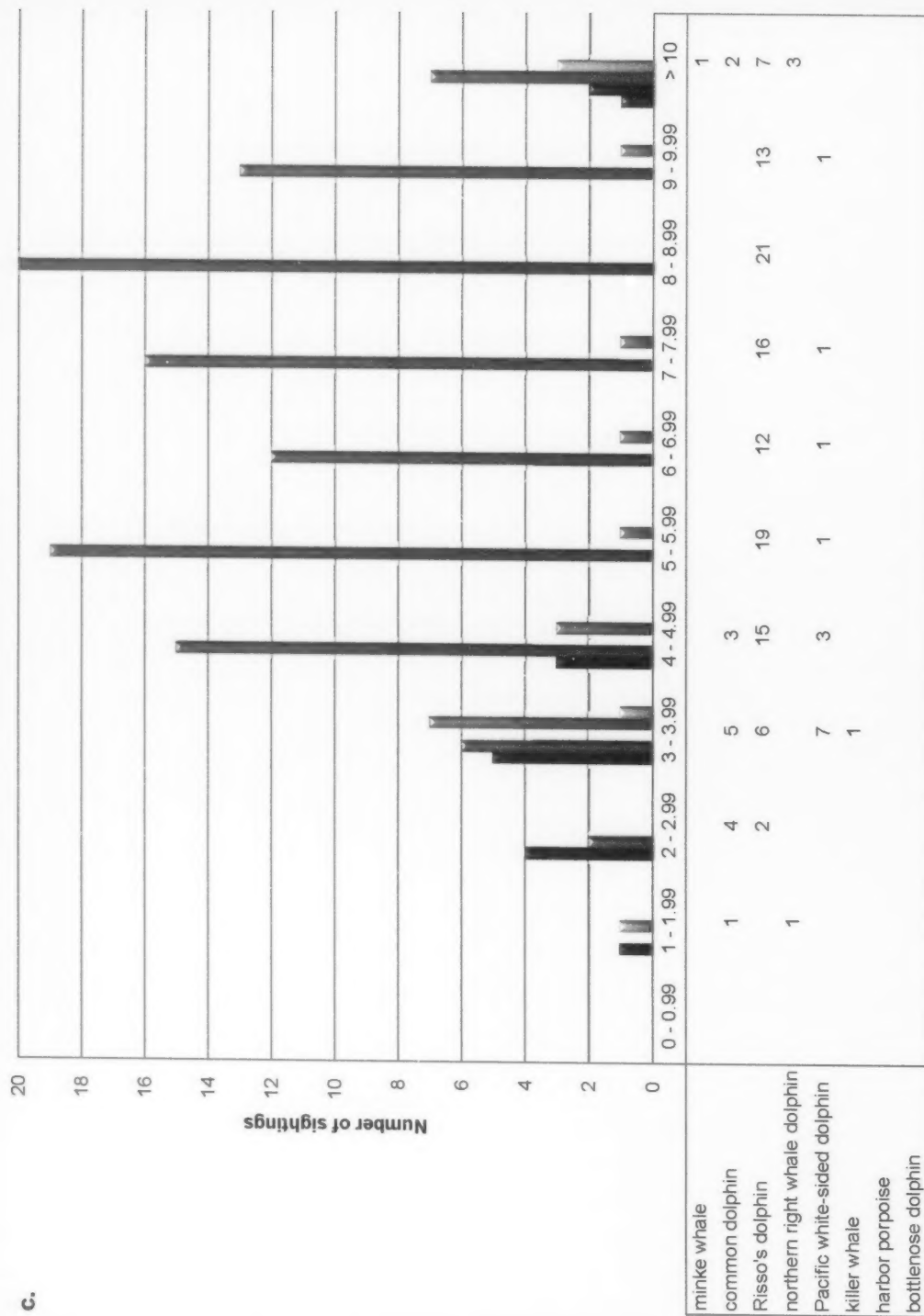


Figure 10. — Cetacean sightings from three research platforms at Granite Canyon: a) observation sheds; b) "Big Eye" binocular watches; and c) aerial surveys operating concurrently in January 1993, 1994, and 1996. Distance bins are in nautical miles (1 n.mi. = 1.85 km).

b.



c.



Forays into waters north of Point Sur during the winter months by common dolphins (Fiscus and Niggol, 1965) and bottlenose dolphins (Wells et al., 1990; Feinholtz, 1996) appeared to be uncommon before the 1982–83 El Niño. The studies by Fiscus and Niggol (1965) and Dohl et al.^{1,2} happened to coincide with strong El Niño events followed by protracted warm periods that lasted well after the tropical signal had disappeared (McGowen et al., 1998; Luch-Belda et al., 2005). These events may explain why a large group of common dolphins was observed well north of our study area, near San Francisco Bay in February 1959 (Fiscus and Niggol, 1965). Common dolphins are considered intermittent visitors to this region and are strongly associated with warmer waters (Benson et al., 2002). Bottlenose dolphins along the California coast have also been described as warm water species (Wells et al., 1990).

In the mid to late 1800's, a prolonged warm water period occurred with a number of moderate to strong El Niño events (Quinn, 1993; Engstrom, 1994). Warmer water fishes moved northward and persisted in the waters near Monterey (Hubbs, 1948). A few specimens (jawbones and skulls) of bottlenose dolphins from this time period were collected near Monterey and San Francisco Bay (Andrews, 1911; Kenyon, 1952; Orr, 1963). Banks and Brownell (1969:269) noted these possible links between warm water events and shifts northward in the range of bottlenose dolphin as they followed their preferred prey.

Risso's dolphins were found year-round in offshore waters of central California but movements inshore seemed to occur during warm periods, particularly where the continental shelf narrows in the Monterey area (Leatherwood et al., 1980; Dohl et al.^{1,2}). Dohl et al.^{1,2} found that in winter Risso's dolphins were in greatest abundance and closer to shore (approaching the 183 m isobath) than during any other season (see also Fig. 6). Pacific white-sided dolphins are also found year-round in the study area (Black, 1994). Black (1994) noted when sea surface temperature anomalies were

Table 9.—Monthly oceanographic anomalies observed during the census of southbound migrating gray whales (1967–2007). The number of warm and cold sea surface temperature (SST) months and negative and positive upwelling indices (UI) months are shown for periods before and after Pacific regime shifts (Mantua et al., 1997; Hare and Mantua, 2000; Benson and Trites, 2002).

Monthly anomaly	Number of census months			Total	p-value
	Before 1977	1977–1989	After 1989		
Warm SST	7	11	17	35	0.003 ¹
Cold SST	20	10	6	36	
Negative UI	20	19	17	56	0.11
Positive UI	7	1	7	15	

¹ = total anomaly months were significantly different among regime periods.

high, Pacific white-sided dolphins were more abundant and closer to the shelf edge. Foraging Pacific white-sided dolphins were also found closer to the shelf edge and in shallower water than during any other activity (Black, 1994:39).

Overview and Conclusions

Shore-based sites south of Carmel were selected for counting gray whales during their southbound migration because these whales pass close to the shore in this area, apparently an effect of having just crossed some deep maritime canyons to the north. Results from these gray whale counts have been published in numerous journals (see Literature Cited section), but a valuable part of the dataset that was ignored in these publications was the record of other cetaceans also seen from these research sites. Although there were unknown numbers of animals missed by shore-based observers, the consistent search effort from early December to mid February with one person searching at a time provides a documentation of sighting rates that can be compared across the 40-year history of this project. Some aspects of the research protocol have changed, especially in the late 1980's with increased emphasis on detailed records of sighting time and location (Laake et al., 2009), but the methodological changes have not significantly altered the search effort.

A consistency in effort has been important to the goals of the gray whale census because accurate estimates of whale abundance and trends require consistent, predictable effort. By following a strict, systematic research protocol, the search effort lends itself to tests of the system, allowing for correction factors that can improve the accuracy of abundance estimates, which is vital for

species management. This uniformity in effort has provided an excellent platform for the current study, documenting cetaceans seen during the gray whale census.

Despite difficulties in detecting and identifying the variety of cetaceans in coastal waters of central California, there seemed to be an increase in the diversity of species and sighting rates through the study period, 1967–2007. Warm periods and El Niño events likely played a role (e.g. Benson et al., 2002; Dohl et al.^{1,2}). The warm period observed during the 1990's (Table 9) may partially explain the increase in sighting rates and diversity observed at the census site compared to the much cooler temperatures of the 1970's. This suggests a response to regime change (e.g. Fiedler, 2002; Chavez et al., 2003) rather than shorter scale variability such as a warm or cool year. Unfortunately, gaps in the census dataset exist during particularly strong El Niño and La Niña events in the 1980's and 1990's. Overall, this time-series is unique in that it spans four decades and provides some insights into cetacean habitat use in central California during winter months.

Acknowledgements

This paper would not be possible without the dedicated observers who spent many hours of many days and months searching the ocean for cetaceans. Observers included: R. Angliss, A. Banks, L. Baraff, S. Benson, J. Bonturi, D. Bown, L. Briggs, G. Carroll, J. Cassidy, J. Cesarone, C. D'Vincent, M. Dahlheim, D. DeMaster, L. J. Dickson, M. Donahue, T. Farley, R. Ferrero, J. Flanders, R. G. Fletcher, N. Fraley, N. Friday, S. Fuhs, L. Gerber, J. Gilpatrick, C. Goebel-Diaz, M. Gosho, F. S. Hill, R. Hobbs, J. Houk, G. Joyce, B.

Krogman, J. Laake, I. M. Laursen, J. Lerczak, J. Lincoln, K. Lodge, S. Marquis, T. Martin, M. Muto, K. Newton, W. Perryman, S. Reif, J. Rochin, J. Rote, D. J. Rugh, S. Savage, M. Scillia, N. Severinghaus, K. E. W. Sheldon, M. Shoemaker, K. Strickland, C. Short, B. Hacker Sinclair, R. Strawn, S. Treacy, L. Tsunoda, A. von Saender, B. Voss, J. Waite, P. White, D. Withrow, A. Wolman, and E. M. Zeman. We thank A. Baldrige for inspiring this study. Aerial surveys were conducted under NMFS permit 791, Monterey Bay National Marine Sanctuary permits 01-92, 01-94, 31-95 and California Department of Fish and Game permit under code section 10501.5. This manuscript benefited greatly from the comments provided by R. L. Brownell, Jr., A. Baldrige, P. J. Clapham, N. A. Friday, L. Fritz, G. Duker, J. Lee, and an anonymous reviewer.

Literature Cited

- Andrews, R. C. 1911. Description of an apparently new porpoise of the genus *Tursiops*, with remarks upon a skull of *Tursiops gillii* Dall. Bull. Amer. Mus. Nat. Hist. 30:233-237.
- Bakun, A., and C. S. Nelson. 1991. The seasonal cycle of wind stress curl in subtropical eastern boundary current regions. J. Phys. Oceanogr. 21:1815-1834.
- Banks, R. C., and R. L. Brownell. 1969. Taxonomy of the common dolphins of the eastern Pacific Ocean. J. Mamm. 50:262-271.
- Benson, A. J., and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish. Fish. 3:95-113.
- Benson, S. R., D. A. Croll, B. B. Marinovic, F. P. Chavez, and J. T. Harvey. 2002. Changes in the cetacean assemblage of a coastal upwelling ecosystem during El Niño 1997-98 and La Niña 1999. Prog. Oceanogr. 54:279-291.
- Black, N. A. 1994. Behavior and ecology of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in Monterey Bay, California. M.Sc. thesis, Moss Landing Marine Lab., San Fran. State Univ., Calif., 133 p.
- _____, A. Schulman-Janiger, R. L. Ternullo, and M. Guerrero-Ruiz. 1997. Killer whales of California and western Mexico: a catalog of photo-identified individuals. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFS-247, 180 p.
- Calambokidis, J., and J. Barlow. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Mar. Mamm. Sci. 20:63-85.
- Carretta, J. V., K. A. Forney, and S. R. Benson. 2009. Preliminary estimates of harbor porpoise abundance in California waters from 2002 to 2007. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFS-435, 10 p.
- Chavez, F. P., J. Ryan, S. E. Lluich-Cota, and C. M. Niquen. 2003. From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science 299:217-221.
- Chivers, S. J., A. E. Dizon, P. J. Gearin, and K. M. Robertson. 2002. Small-scale population structure of eastern North Pacific harbour porpoises (*Phocoena phocoena*) indicated by molecular genetic analyses. J. Cetacean Res. Manage. 4(2):111-122.
- Croll, D. A., B. Marinovic, S. Benson, F. P. Chavez, N. Black, R. Ternullo, and B. R. Tershy. 2005. From wind to whales: trophic links in a coastal upwelling system. Mar. Ecol. Prog. Ser. 289:117-130.
- Dorsey, E. M., S. J. Stern, A. R. Hoelzel, and J. Jacobsen. 1990. Minke whale (*Balaenoptera acutorostrata*) from the west coast of North America: individual recognition and small-scale site fidelity. Rep. Int. Whal. Comm. Spec. Iss. 12:357-368.
- Engstrom, W. N. 1994. Nineteenth-century coastal gales of southern California. Geogr. Rev. 84:306-315.
- Feinholz, D. M. 1996. Pacific coast bottlenose dolphins (*Tursiops truncatus gilli*) in Monterey Bay, California. M.S. thesis, Moss Landing Marine Lab., San Jose State Univ., Calif., 78 p.
- Fiedler, P. C. 2002. Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. Mar. Ecol. Prog. Ser. 244:265-283.
- Fiscus, C. H., and K. Niggol. 1965. Observations of cetaceans off California, Oregon and Washington. U.S. Dep. Inter., Fish Wildl. Serv. Spec. Sci. Rep. Fish. 498, 27 p.
- Forney, K. A. 1997. Patterns of variability and environmental models of relative abundance for California cetaceans. Ph.D. dissert., Univ. Calif., San Diego, 130 p.
- _____. 1999. Trends in harbor porpoise abundance off central California 1986-95: evidence for interannual changes in distribution? J. Cetacean Res. Manage. 1:73-80.
- _____, D. A. Hanan, and J. Barlow. 1991. Detecting trends in harbor porpoise abundance from aerial surveys using analysis of covariance. Fish. Bull. 89:367-377.
- _____, J. Barlow, and J. V. Carretta. 1995. The abundance of cetaceans in California waters. Part II: aerial surveys in winter and spring of 1991 and 1992. Fish. Bull. 93:15-26.
- Greene, H. G., N. M. Maher, and C. K. Paull. 2002. Physiography of the Monterey Bay National Marine Sanctuary and implications about continental margin development. Mar. Geol. 181:55-82.
- Hansen, L. J. 1990. California coastal bottlenose dolphins. In S. Leatherwood and R. R. Reeves (Editors), The bottlenose dolphin, p. 403-420. Acad. Press, San Diego, Calif.
- Hanson, M. T., and R. H. Defran. 1993. The behaviour and feeding ecology of the Pacific coast bottlenose dolphin, *Tursiops truncatus*. Aquat. Mamm. 19:127-142.
- Hare, S. R., and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47(2-4):103-146.
- Hernandez-Vazquez, S. 1994. Distribution of eggs and larvae from sardine and anchovy off California and Baja California, 1951-1989. Calif. Coop. Ocean Fish. Invest. Rep. 35:94-107.
- Heyning, J. E., and W. F. Perrin. 1994. Evidence for two species of common dolphin (*genus Delphinus*) from the eastern North Pacific. Nat. Hist. Mus. Los Angel. Cty. Sci. Ser. 442:1-35.
- Hubbs, C. L. 1948. Changes in the fish fauna of western North America correlated with changes in ocean temperature. J. Marine Res. 7:459-482.
- Keiper, C. A., D. G. Ainley, S. G. Allen, and J. T. Harvey. 2005. Marine mammal occurrence and ocean climate off central California, 1986 to 1994 and 1997 to 1999. Mar. Ecol. Prog. Ser. 289:285-306.
- Kenyon, K. W. 1952. A bottlenose dolphin from the California coast. J. Mamm. 33:385-387.
- Laake, J., A. Punt, R. Hobbs, M. Ferguson, D. Rugh, and J. Breiwick. 2009. Re-analysis of gray whale southbound migration surveys, 1967-2006. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-203, 55 p.
- Leatherwood, S., W. F. Perrin, V. L. Kirby, C. L. Hubbs, and M. Dahlheim. 1980. Distribution and movements of Risso's dolphin, *Grampus griseus*, in the eastern North Pacific. Fish. Bull. 77(4):951-963.
- _____, and R. R. Reeves. 1982. Bottlenose dolphin *Tursiops truncatus* and other toothed cetaceans. In J. A. Chapman and G. A. Feldhammer (Editors), Wild mammals of North America: biology, management, economics, p. 369-414. John Hopkins Univ. Press, Baltimore, Md.
- _____, R. R. Reeves, W. F. Perrin, and W. E. Evans. 1982. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent Arctic waters. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-CIRC 444, 245 p.
- Lluch-Belda, D., R. M. Laurs, D. B. Lluich-Cota, and S. E. Lluich-Cota. 2001. Long-term trends of interannual variability in the California current system. Calif. Coop. Ocean. Fish. Invest. Rep. 42:129-144.
- _____, D. B. Lluich-Cota, and S. E. Lluich-Cota. 2003. Scales of interannual variability in the California current system: associated physical mechanisms and likely ecological impacts. Calif. Coop. Ocean. Fish. Invest. Rep. 44:76-85.
- _____, _____, and _____ 2005. Changes in marine faunal distributions and ENSO events in the California current. Fish. Oceanogr. 14:458-467.
- Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteor. Soc. 78:1069-1079.
- McGowan, J. A., D. R. Cayan, and L. M. Dorman. 1998. Climate-ocean variability and ecosystem response in the northeast Pacific. Science 281:210-217.
- Orr, R. T. 1963. A northern record for the Pacific bottlenose dolphin. J. Mamm. 44:424.
- Quinn, W. H. 1993. The large-scale ENSO event, the El Niño and other important regional features. Bull. Inst. Fr. Études Andines 22:13-34.
- Reichow, D., and M. J. Smith. 2001. Microsatellites reveal high levels of gene flow among population of the California squid *Loligo opalescens*. Mol. Ecol. 10:1101-1109.
- Reilly, S. B., D. W. Rice, and A. A. Wolman. 1983. Population assessment of the gray whale, *Eschrichtius robustus*, from California shore censuses, 1967-80. Fish. Bull. 81:267-281.
- Rice, D. W., and A. A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Spec. Publ. No. 3, Am. Soc. Mammalogists.

- Rugh, D., R. Ferrero, and M. Dahlheim. 1990. Inter-observer count discrepancies in a shore-based census of gray whales (*Eschrichtius robustus*). *Mar. Mammal Sci.* 6(2):109-120.
- _____, K. E. W. Shelden, and A. Schulman-Janiger. 2001. Timing of the southbound migration of gray whales. *J. Cetacean Res. Manage.* 3:31-39.
- _____, R. C. Hobbs, J. A. Lerczak, and J. M. Breiwick. 2005. Estimates of abundance of the eastern North Pacific stock of gray whales (*Eschrichtius robustus*) 1997-2002. *J. Cetacean Res. Manage.* 7:1-12.
- _____, J. A. Lerczak, R. C. Hobbs, J. M. Waite, and J. L. Laake. 2002. Evaluation of high-powered binoculars to detect inter-year changes in offshore distribution of gray whales. *J. Cetacean Res. Manage.* 4:57-61.
- Shelden, K. E. W., and J. L. Laake. 2002. Comparison of the offshore distribution of southbound migrating gray whales from aerial survey data collected off Granite Canyon, California, 1979-96. *J. Cetacean Res. Manage.* 4:53-56.
- _____, D. J. Rugh, and A. Schulman-Janiger. 2004. Gray whales born north of Mexico: indicator of recovery or consequence of regime shift? *Ecol. Appl.* 14:1789-1805.
- _____, A. Baldrige, and D. E. Withrow. 1995. Observations of Risso's dolphins, *Grampus griseus*, with gray whales, *Eschrichtius robustus*. *Mar. Mamm. Sci.* 11(2):231-240.
- Spratt, J. D. 1979. Age and growth of the market squid, *Loligo opalesces* Berry, from statoliths. *Calif. Coop. Ocean. Fish. Invest. Rep.* 20:58-63.
- Stern, S. J. 1992. Surfacing rates and surfacing patterns of minke whales (*Balaenoptera acutorostrata*) off central California, and the probability of a whale surfacing within visual range. *Rep. Int. Whal. Comm.* 42:379-385.
- Sund, P. N., and J. L. O'Connor. 1974. Aerial observations of gray whales during 1973. *Mar. Fish. Rev.* 36(4):51-52.
- Wells, R. S., L. J. Hansen, A. Baldrige, T. P. Dohl, D. L. Kelly, and R. H. DeFran. 1990. Northward extension of the range of bottlenose dolphins along the California coast. In S. Leatherwood and R. R. Reeves (Editors), *The bottlenose dolphin*, p. 421-431. Acad. Press, San Diego, Calif.
- Wing, B. L., and R. W. Mercer. 1990. Temporary northern range extension of the squid *Loligo opalesces* in Southeast Alaska. *Veliger* 33:238-240.
- _____, J. M. Murphy, and T. L. Rutecki. 2000. Occurrence of Pacific sardine, *Sardinops sagax*, off southeastern Alaska. *Fish. Bull.* 98:881-883.

Fishery-independent Bottom Trawl Surveys for Deep-water Fishes and Invertebrates of the U.S. Gulf of Mexico, 2002–08

MARK A. GRACE, BRANDI NOBLE, WALTER INGRAM, ADAM POLLACK, and ALONZO HAMILTON

Introduction

Since before the first European settlers arrived to colonize the U.S. Gulf of Mexico (GOM) coast, fishery resources played an important role for sustaining indigenous peoples (Swanton, 1979; Gore, 1992) and later were a vital food source for nonindigenous immigrant populations (Sullivan, 1985). As human populations expanded and protein demands from the sea increased (along with market opportunities for a broader variety of consumer choices due to diverse ethnicity), harvesting seafood ranged from near-shore to coastal, then eventually further offshore.

In addition to offshore expansion of directed fisheries, mineral exploration

and production (e.g. petroleum and natural gas) expanded from coastal to offshore areas as technologies kept pace with demands of the commercial industry (Managi et al., 2005). The potential for further expansion of mineral-resource exploration and extraction into deep waters of the GOM is evidenced by many active oil and gas platforms already in service, and by the geographic range of active leases and approved applications for future development of continental shelf and outer continental shelf waters (Fig. 1).

Considering the possibility of GOM offshore fisheries gaining a more prominent role for fulfilling increasing protein demands, and the scenario that offshore GOM fisheries could eventually be impacted by a variety of anthropogenic factors (e.g. the hypoxic zone of the north-central GOM and expansion of the offshore petroleum and natural gas industry), Mississippi Laboratories (MSL) of NOAA's NMFS/SEFSC, initiated a baseline fishery-independent project to document offshore-fisheries dynamics for deep-water bottom fishes and invertebrates captured with bottom trawls. Potential sources of survey bias (as related to survey design and gear type), are controlled by use of a standardized-random survey design and standardized survey gear.

Materials and Methods

Deep-water trawl surveys were conducted during October and November of each survey year (in general over a 6-wk period). The survey area spanned most of the GOM exclusive of prohibited areas and shipping lanes with significant vessel traffic (Fig. 1). The survey design

utilized proportional allocation based on the width of GOM continental shelf and outer continental shelf waters.

Bottom trawl locations were randomly selected within 21 statistical zones (ranging from shore to the economic exclusive zone boundary) of 60° latitude (for north to south oriented shorelines) or longitude (for east to west oriented shorelines); some statistical zones were irregular-sized due to irregular shore contours. In general, bottom depths for station allocations ranged from 110–500 m (2002), 90–500 m (2003), and 50–500 m (2004, 2006, 2007, and 2008); however, depending on ancillary survey objectives (e.g. gear comparison study), sea conditions, or steep bottom depth contours some bottom trawl locations were in bottom depths < 50 m or > 500 m.

Prior to gear deployment the sea bottom was evaluated with echosounders to determine suitability for bottom trawling. If a bottom profile appeared prohibitive for bottom trawling (based on visual assessments of bottom-bathymetry irregularities or steep bottom inclines), the preselected station was not sampled. Sampling sites were occupied during any time period (24-h/day sampling) and were not designated as day or night sites prior to the survey, and were occupied in the most time-efficient manner possible.

The trawl sampling gear consisted of a two-seam bottom trawl (27.4 m length footrope), fished with W-style trawl doors (682 kg each, 3.5 m²). The trawl opening averaged 15.5 m width by 10.0 m height, the codend mesh liner was 4.0 mm, and the trawl speed was 6.3 km/h (speed over sea floor). Bottom trawls

M. A. Grace, B. Noble, W. Ingram, A. Pollack and A. Hamilton are with the Mississippi Laboratories, Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, P.O. Drawer 1207, Pascagoula, MS 39568-1207. Corresponding author is M. A. Grace (Mark.A.Grace@noaa.gov).

ABSTRACT—From 2002 through 2008, the Mississippi Laboratories of the NMFS Southeast Fisheries Science Center, NOAA, conducted fishery-independent bottom trawl surveys for continental shelf and outer-continental shelf deep-water fishes and invertebrates of the U.S. Gulf of Mexico (50–500 m bottom depths). Five-hundred and ninety species were captured at 797 bottom trawl locations. Standardized survey gear and randomly selected survey sites have facilitated development of a fishery-independent time series that characterizes species diversity, distributions, and catch per unit effort. The fishery-independent surveys provide synoptic descriptions of deep-water fauna potentially impacted by various anthropogenic factors.

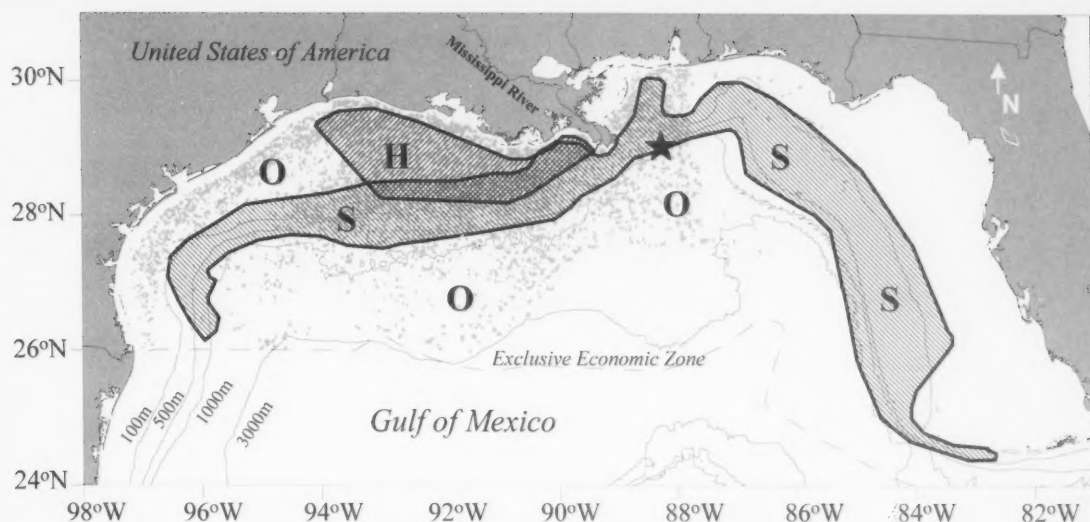


Figure 1.—Deep-water bottom trawl survey area (S); approximate area of the predicted 2008 hypoxic zone (H); offshore locations of active petroleum and natural gas platforms (O) including approved applications to drill (locations are represented by small-gray dots); Deepwater Horizon Macondo/MC252 exploration oil platform (★).

were 30-min duration once the trawl settled on bottom (as determined by net mensuration systems or trawl descent rate charts).

At termination of the 30-min trawl, the ship pulsed speed to 10.5 km/h for 5 min to flush catch from the trawl through a web-constructed fish funnel and into the trawl codend, then the trawl was hauled. After hauling, the catch was weighed either by individual baskets or, for relatively large catches, by use of a remotely-controlled electronic scale (dynamometer) used to weigh the entire trawl codend with catch; the trawl codend weight was subtracted from the total weight. Environmental sampling was conducted at each trawl location and included profiles of sea-surface to sea-bottom environmental parameters: temperature, salinity, dissolved oxygen, transmissivity (turbidity), and indirect measures of chlorophyll-*a* via a fluorometer.

Results

From 2002 to 2008, six deep-water bottom trawl surveys were conducted in the GOM; sampling did not occur during 2005. Bottom trawl effort (797 tows,

398 h 30 min total tow time) resulted in the capture of 590 species (finfish, noncrustacean invertebrates, and crustaceans collectively), representing 54 orders, 192 families, and 373 genera (Table 1). Total catch weight for all groups collectively was 74,987 kg; finfish were the primary catch component (94.2%), followed by noncrustacean invertebrates (5.2%), and crustaceans (0.6%). For the finfish catch component ranked by weight (Table 2), 22.8% was rough scad, *Trachurus lathami*, which was also the top ranked by number and weight for all groups collectively; followed by gulf butterfish, *Peprilus burti*, 13.5%; and longspine porgy, *Stenotomus caprinus*, 10.7%.

One of the most important finfish species of GOM management concern, the red snapper, *Lutjanus campechanus*, was ranked 27th by weight within the finfish group. The top-ranked elasmobranch by weight (finfish group) was the Atlantic angel shark, *Squatina dumeril*, ranked 6th, followed by the rougtail stingray, *Dasyatis centroura*, ranked 13th. Of 44 finfish orders known to occur in the GOM, 32 (73%) were represented during the surveys.

Table 1.—Catch summary for finfish, noncrustacean invertebrates, and crustaceans, from deep-water bottom trawl surveys, 2002–08.

Category	Finfish	Noncrustacean invertebrates	Crustaceans	Total
Orders	32	14	8	54
Families	124	25	43	192
Genera	260	34	79	373
Species	445	39	106	590

For the noncrustacean invertebrate catch component ranked by weight (Table 3), 73.8% were longfin squid, *Loligo pealeii*, also the highest percent frequency of occurrence of total trawls for all groups collectively; 21.9% were southern shortfin squid, *Illex coindetii*, and 2.7% were arrow squid, *Loligo plei*. For the crustacean catch component ranked by weight (Table 4), 33.0% were brown shrimp, *Farfantepenaeus aztecus*, followed by the longspine swimming crab, *Portunus spinicarpus*, 12.0%, and the rose shrimp, *Parapenaeus politus*, 7.3%. In addition to commercially important brown shrimp, three other commercially important shrimp (ranked within the crustacean group) were royal red shrimp, *Pleoticus robustus*, 4.4%; pink shrimp, *Farfantepenaeus duorarum*, 1.1%; and white shrimp, *Litope-*

Table 2.—Finfish (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
<i>Trachurus lathami</i> , rough scad	16,138	264,273	69.4	30–497/36	8.8–28.7/18.2	31.0–36.6/36.2	2.8–8.0/4.3
<i>Peprilus burti</i> , gulf butterfish	9,499	135,268	34.3	42–347/117	11.0–28.7/19.1	28.2–36.6/36.2	2.8–8.0/4.3
<i>Stenotomus caprinus</i> , longspine porgy	7,606	158,951	31.1	30–178/100	15.2–28.7/20.3	28.2–36.6/36.3	2.8–8.0/4.5
<i>Pristipomoides aquilonaris</i> , wenchman	4,329	68,327	64.1	48–481/136	9.1–28.7/18.0	28.2–36.6/36.1	3.4–8.0/4.2
<i>Etrumeus teres</i> , round herring	3,746	158,928	18.3	54–239/132	14.0–24.7/17.9	31.0–36.6/36.2	3.5–6.7/4.1
<i>Squatina dumeril</i> , Atlantic angel shark	2,297	783	36.6	41–423/165	10.1–25.7/16.5	34.6–36.7/36.0	3.4–6.4/4.1
<i>Saurida normani</i> , shortjaw lizardfish	2,168	30,359	38.4	53–355/152	10.2–25.2/17.0	34.6–36.7/36.1	3.4–6.4/4.1
<i>Lagodon rhomboides</i> , pinfish	2,162	24,742	22.1	30–209/94	15.6–28.7/21.3	28.2–36.6/36.2	2.8–6.7/4.6
<i>Trichiurus lepturus</i> , Atlantic cutlassfish	2,016	26,430	25.6	47–341/115	12.0–28.7/19.5	28.2–36.6/36.2	2.8–6.7/4.4
<i>Micropogonias undulatus</i> , Atlantic croaker	1,940	21,904	10.4	42–141/71	16.0–28.7/23.3	35.6–36.6/36.4	2.8–6.4/4.9

Table 3.—Noncrustacean invertebrates (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
<i>Loligo pealeii</i> , longfin squid	2,872	73,028	78.9	30–563/150	8.4–27.9/17.4	28.2–36.7/36.0	3.4–8.0/4.2
<i>Illex coindetii</i> , southern shortfin squid	852	5,881	13.9	128–563/297	8.4–19.7/12.8	33.1–36.6/35.6	3.4–4.6/3.9
<i>Loligo plei</i> , arrow squid	105	7,826	8.3	39–213/98	13.5–28.7/21.5	34.3–36.7/36.3	3.4–6.7/5.0
<i>Octopus vulgaris</i> , common octopus	13	85	5.1	39–189/116	9.3–26.1/19.2	35.1–36.7/36.3	3.5–6.5/4.5
<i>Amusium papyraceum</i> , paper scallop	5	459	5.0	55–132/89	16.7–27.7/21.1	36.2–36.6/36.4	3.4–6.3/4.7
<i>Tonna galea</i> , giant tun	5	16	0.9	130–176/151	14.4–17.4/16.1	34.6–36.3/35.9	3.6–4.3/3.9
<i>Pholidoteuthis adami</i> , pink scaled squid	4	14	0.5	373–563/480	8.4–13.9/10.0	33.2–35.8/34.5	3.5–4.2/3.8
<i>Abralia redfieldi</i> (no common name)	2	995	7.3	69–516/246	8.7–24.7/14.2	34.5–36.6/35.8	3.4–6.7/4.0
<i>Illex oxygonius</i> , sharptail shortfin squid	2	10	0.4	172–444/270	8.9–16.0/13.0	35.1–36.1/35.7	3.8–4.0/3.9
<i>Semiosquilla equalis</i> , greater shining bobtail	2	574	11.5	59–436/153	9.5–25.7/17.2	35.0–36.6/35.8	3.5–6.9/4.2

Table 4.—Crustaceans (top 10 ranked by weight) captured during deep-water bottom trawl surveys, 2002–08. Depth, temperature, salinity, and oxygen saturation values are minimum-maximum/mean.

Taxon	Total wt. (kg)	Total no.	% Frequency of occurrence	Depth (m)	Temp. (°C)	Salinity (ppt)	Oxygen (mg/l)
<i>Farfantepenaeus aztecus</i> , brown shrimp	163	5,255	13.8	48–144/86	16.1–28.7/21.5	35.5–36.6/36.3	3.3–6.7/4.8
<i>Portunus spinicarpus</i> , longspine swimming crab	59	6,968	26.1	46–217/125	14.2–27.0/18.7	34.6–36.7/36.1	3.4–8.0/4.3
<i>Parapenaeus politus</i> , rose shrimp	36	21,227	18.1	51–436/164	10.2–28.7/16.6	34.5–36.6/35.8	3.4–8.0/4.1
<i>Solenocera vioscai</i> , humpback shrimp	25	7,267	29.9	41–337/144	9.5–28.7/17.7	34.3–36.6/36.0	3.4–8.0/4.2
<i>Calappa sulcata</i> , yellow box crab	25	86	4.0	48–166/97	16.3–27.7/21.1	28.2–36.6/36.1	3.6–6.3/4.6
<i>Pleoticus rodustus</i> , royal red shrimp	22	431	3.4	201–563/416	8.4–15.2/10.3	33.1–36.0/35.1	3.5–9.0/3.8
<i>Stenocionops spinosissimus</i> , tenspined spider crab	20	33	3.4	103–418/168	10.1–19.2/16.1	33.3–36.5/36.1	3.5–4.4/4.0
<i>Penaeopsis serrata</i> , pinkspotted shrimp	11	7,760	10.3	41–516/200	8.7–25.7/15.9	34.3–36.6/36.0	3.4–6.4/4.1
<i>Anasimus latus</i> , stilt spider crab	10	985	13.2	52–314/133	10.2–27.0/18.0	28.2–36.6/36.2	3.5–5.9/4.1
<i>Sicyonia brevirostris</i> , brown rock shrimp	8	460	3.9	46–134/69	17.1–28.0/23.2	35.9–36.6/36.4	3.5–6.4/5.1

naeus setiferus, 0.3%. Distribution of the top-ranked by weight rough scad (for the finfish group) and longfin squid (for the non-invertebrate crustacean group), was relatively uniform across the survey area in bottom depths 100–500 m; distribution of the top-ranked by weight brown shrimp (for the crustacean group) was primarily west of long. 88°W in bottom depths 30–200 m.

Discussion

The importance of developing a fishery-independent time series for assessing life histories and distributions is of particular significance for popula-

tions that are unexploited or minimally exploited (Johnson, 1994; Jennings and Blanchard, 2004). On a global basis, with many fisheries fully exploited or nearing full exploitation due to increasing demands for fishery products (FAO, 2004), with regards to outer-continental shelf bottom fishes and invertebrates, the MSL GOM survey represents a rare opportunity to assess species-specific population dynamics from a largely unexploited geographic region.

Even though the variety of factors potentially affecting deep-water fish and invertebrate GOM populations overlap those in other global regions, three

primary factors are encompassed (to varying degrees) within the geographic range of the MSL GOM deep-water trawl surveys: the north-central GOM hypoxic zone, the probable expansion of fisheries offshore into deep waters (in particular bottom-trawl prosecuted fisheries), and the offshore petroleum and natural gas industry.

One of the world's most extensive hypoxic zones (dissolved oxygen concentration < 2.0 mg/l) is found along the GOM north-central coast (Rabalais et al., 1999, 2002a; Fig. 1). Hypoxic-zone dynamics are influenced by the Mississippi River (flow rate 14,000 m³/

sec, Bratkovich et al., 1994), and effects of the hypoxic zone are varied and can include species displacement and eutrophication (Rabalais et al., 2002b) on both small and large geographic scales. It is common for the GOM-hypoxic zone to extend from near shore to well offshore to bottom depths of 60 m (Rabalais et al., 2007). Even though hypoxic conditions were not recorded from any of the MSL bottom trawl locations, some of the dissolved oxygen levels were as low as 2.8 mg/l (Table 2).

During peak hypoxic events from June through August (hypoxic conditions have been recorded from late February to October (Rabalais et al., 2002a)), the effects on continental-shelf and outer-continental shelf fishes can be especially pronounced, and this in turn can affect the distribution, abundance, and behavior of fish (Stanley and Wilson, 2004) and invertebrates (Leming and Stuntz, 1984; Craig et al., 2005). Since the hypoxic zone is dependent in part on Mississippi River effluent that often contains various amounts of hypoxic precursors (i.e. nitrogen and phosphorus from fertilizer use (Diaz, 2001; Rabalais et al., 2002a)), the likelihood exists that the GOM hypoxic phenomena will continue to influence fish and invertebrate distributions and their associated trophic relationships in the north-central GOM.

According to a Louisiana Universities Marine Consortium Press Release¹, the predicted size of the 2008 hypoxic zone (Fig. 1) was one of the largest in area on record (22,790 km²) and was attributed to a 37% increase above the 2007 nitrate-nitrogen loading level of the Mississippi River (the highest level since measurements began in 1970); the press release also stated that increased farming of more land for the production of biofuels contributed to the 2008 increased nitrogen-loading rate.

Even though the actual size for the 2008 hypoxic zone was less than predicted due to a number of contributing

factors², the potential for significant annual hypoxic events remains likely for the north-central GOM. Prior to 1993, the average areal extent of the hypoxic zone was 8,000–9,000 km² (Rabalais et al., 1999), therefore, during various years since 1993 the hypoxic zone has more than doubled in size³, and has continued to expand westward⁴ and further offshore toward the deep waters of the outer-continental shelf.

As many commercial marine fisheries continue to decline on a global basis (Pauly et al., 2005), it stands to reason that the search for additional fishery resources will be driven by market incentives (Pauly et al., 2003). As fisheries-harvesting technology continues to improve (Pauly et al., 2002), offshore deep-water fishery resources are increasingly accessible to harvesting (Moore, 1999). Globally, the mean fishing depth for bottom fisheries has increased since 1950 (Morato et al., 2006), and in all likelihood the trend eventually will apply to GOM deep-water bottom fisheries.

Even though the various species prone to capture by deep-water offshore GOM trawl fisheries are relatively unexploited at present (landings are primarily from the Florida GOM coast⁵), there is a GOM-wide fisheries complex of potential exploitation: the coastal-pelagic fishes (estimated biomass 2,928,000 t (Brown et al., 1999, Table 5)). However, the effects of fishing on relatively unexploited populations are often difficult to quantify (Jennings and Blanchard, 2004; Morato et al., 2006;

Table 5.—Coastal pelagic finfish species from Brown et al. (1999) in common with deep-water bottom trawl surveys.

Taxon
<i>Sardinella aurita</i> , Spanish sardine
<i>Opisthonema oglinum</i> , Atlantic thread herring
<i>Decapterus punctatus</i> , Round scad
<i>Trachurus lathami</i> , Rough scad
<i>Harengula jaguana</i> , Scaled sardine
<i>Etrumeus leres</i> , Round herring
<i>Chloroscombrus chrysurus</i> , Atlantic bumper
Engraulidae, Anchovies (general category)
<i>Ariomma bondi</i> , Silver-rag
<i>Pepilurus burti</i> , Gulf butterfish

Anderson et al., 2008) and equally difficult to qualify (Moore, 1999; Pauly et al., 1999; Watson and Pauly, 2001), a situation that is often complicated when offshore fishery-dependent landings are grouped in non-specific generically-broad categories.

The range of effects on deep-water GOM fish and invertebrate populations from offshore petroleum and natural gas structures includes increased offshore structures (3,740 active platforms⁶) possibly enhancing desirable habitats and productivity for a variety of species (Keenan et al., 2007; Shipp and Bortone, 2009), altered fish and invertebrate distributions (Lindberg, 1997; Stanley and Wilson, 2003; Sammarco et al., 2004; Shipp and Bortone, 2009), and benthic-organism responses to associated hydrocarbons (Montagna and Harper, 1996; Peterson et al., 1996).

The likely expansion of the offshore petroleum and natural gas industry is reflected in a report released by the U.S. Department of the Interior⁶; in 2007 approximately 72% of GOM oil production and 54% of GOM leases were in water depths greater than 305 m. For what is classified as approved applications to drill (37,293 applications⁷), 90% of applications are in bottom depths 0–200 m, 3% from 201–400 m, 2% from 401–800 m, 1% from 801–1,000

¹NOAA News Releases, 27 July 2009, Smaller than expected, but severe, dead zone in Gulf of Mexico (online at <http://www.gulfhypoxia.net/News/default.asp?XMLFilename=200908111033.xml>).

²2009 Forecast of the summer hypoxic zone size, northern Gulf of Mexico (online at http://www.gulfhypoxia.net/research/ShelfwideCruises/2009/Files/2009_Hypoxia_Forecast.pdf).

³2009 Real-time environmental monitoring from a wind farm platform in the Texas hypoxia zone (online at <http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fstamp%2Fstamp.jsp%3Ftp%3D%26arnumber%3D5422304&authDecision=-203>).

⁴2008 Florida Fish and Wildlife landing statistics (online at http://research.myfwc.com/features/view_article.asp?id=19224).

⁶U.S. Department of the Interior, Minerals Management Service, Office of Public Affairs, 2008, (OCS Report MMS 2008-013, Deepwater Gulf of Mexico 2008: America's Offshore Energy Future).

⁷U.S. Department of the Interior, Minerals Management Service, 2009a, Gulf of Mexico Fast Facts, April 2009 (online at <http://www.gomr.mms.gov/homepg/fastfacts/WaterDepth/WaterDepth.html>).

¹LUMCOM, 28 July 2008, Dead Zone Again Rivals Record Size (online at <http://www.gulfhypoxia.net/news/documents/HypoxiaForecast13July2008.pdf>).

m, and 4% (or 1,501 applications) from deeper than 1,000 m. Additionally, 13 bids were received for the 181 South Area offshore of the central GOM⁸ with maximum bottom depths for available leases exceeding 3,000 m.

Conclusion

The importance of the MSL GOM deep-water bottom trawl surveys is firmly established when considering various anthropogenic factors that potentially affect population dynamics of continental shelf and outer-continental shelf marine species (the expanding hypoxic zone, offshore expansion of fisheries, offshore petroleum and natural gas industry). Since the deep-water trawl surveys do not target specific species and employ a randomized survey design with standardized survey gear, the time series is applicable as a fishery-independent index for several key species that are of historic and future concern. Potential sources of survey bias are controlled as best they can be considering the limitations of the annual survey period (October and November), the geographic extent and bottom depth range (limited by survey logistics as a function of sea-day allocation), and gear selectivity (deep-water fish trawls are not ideally suited for efficient capture of all species or the sampling of all habitats (Herring, 2004)). As additional anthropogenic factors continue to influence the GOM, the MSL GOM deep-water fishery-independent time series will contribute to important synoptic summaries of the abundance and distribution of biological communities.

Deepwater Horizon Macondo/MC252 Oil Spill

On 20 April 2010, there was a north-central Gulf of Mexico oil spill (50 n.mi. southeast of the Mississippi River delta, Fig. 1) from a deep-water exploration oil platform (Deepwater Horizon Macondo/MC252, 1,523 m bottom depth). The oil-

spill event spanned 91 days and at one point led to a fishery closure by NOAA that comprised 33.2% of Gulf of Mexico Federal waters.⁹ The annual deep-water trawl surveys conducted by Mississippi Laboratories will be an important time-series component for assessing potential oil-spill related anthropogenic effects on marine fauna.

Acknowledgments

Special thanks are extended to MSL personnel John Moser, Butch Pellegrin, David Hanisko, Lagena Fantroy, William Driggers, Terry Henwood, and Lisa Desfosse for assisting with literature searches, developing data summaries and graphics, or conducting manuscript reviews. Ruth Mullins and Steve DiMarco (both of Texas A&M University) and Nancy Rabalais (Louisiana Universities Marine Consortium) provided literature or literature advice and helped clarify hypoxic zone specifics. Chris Gledhill (MSL) was instrumental for planning and conducting the deep-water bottom trawl survey pilot studies, and Dean Landi (formerly of MSL) provided expertise during surveys and in the laboratory. Paula Rychtar and Scott Noble are recognized for their vital supportive efforts. This article was based on its oral presentation for the "Issues Confronting the Deep Oceans," ICES Symposia in May, 2009, at Horta, Azores, Portugal.

Literature Cited

- Anderson, C. N. K., C. Hsieh, S. A. Sandin, R. Hewitt, A. Hollowed, J. Beddington, R. M. May, and G. Sugihara. 2008. Why fishing magnifies fluctuations in fish abundance. *Nature* 452:835–839.
- Bratkovich, A., S. P. Dinner, and D. A. Goolsby. 1994. Variability and prediction of freshwater and nitrate fluxes for the Louisiana-Texas shelf: Mississippi and Atchafalaya River source functions. *Estuaries* 17:766–778.
- Brown, B., J. A. Browder, J. Powers, and C. D. Goodyear. 1999. Biomass, yield models, and management strategies for the Gulf of Mexico ecosystem. In H. Kumpf, K. Steidinger, and K. Sherman (Editors), *The Gulf of Mexico Large Marine Ecosystem*, p. 534–564. Blackwell Sci., Inc., Malden, Mass.
- Craig, J. K., L. B. Crowder, and T. A. Henwood. 2005. Spatial distribution of brown shrimp (*Farfantepenaeus aztecus*) on the northwest-ern Gulf of Mexico shelf: effects of abundance and hypoxia. *Can. J. Fish. Aquat. Sci.* 62:1295–1308.
- Diaz, R. 2001. Overview of hypoxia around the world. *J. Environ. Qual. [Symp. Pap.]* 30(2):275–281.
- FAO. 2004. The state of world fisheries and aquaculture. Food Agric. Organ. U. N., Rome, 153 p.
- Gore, R. H. 1992. The Gulf of Mexico: a treasury of resources in the American Mediterranean. Pineapple Press, Inc., Sarasota, Fla., 384 p.
- Herring, P. J. 2004. Exploring the life in the ocean: how do we know what is there? *BioScience* 54(1):1–12.
- Johnson, L. 1994. Long-term experiments on the stability of two fish populations in previously unexploited arctic lakes. *Can. J. Fish. Aquat. Sci.* 51:209–225.
- Jennings, S., and J. L. Blanchard. 2004. Fish abundance with no fishing: predictions based on macroecological theory. *J. Animal Ecol.* 73:632–642.
- Keenan, S. F., M. C. Benfield, and J. K. Blackburn. 2007. Importance of the artificial light field around offshore petroleum platforms for the associated fish community. *Mar. Ecol. Prog. Ser.* 331:219–231.
- Leming, T. D., and W. E. Stuntz. 1984. Zones of coastal hypoxia revealed by satellite scanning have implications for strategic fishing. *Nature* 310:136–138.
- Lindberg, W. J. 1997. Can science resolve the attraction-production issue? *Fisheries* 22:10–13.
- Managi, S., J. J. Opoluch, D. Jin, and T. A. Grigalunas. 2005. Technological change and petroleum exploration in the Gulf of Mexico. *Energy Policy* 33(5):619–632.
- Montagna, P. A., and D. E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.* 53:2567–2588.
- Moore, J. A. 1999. Deep-sea finfish fisheries: lessons from history. *Fish. Manage.* 24:16–21.
- Morato, T., R. Watson, T. J. Pitcher, and D. Pauley. 2006. Fishing down the deep. *Fish and Fish.* 7:24–34.
- Pauly, D., F. Arreguin-Sanchez, J. Browder, V. Christensen, S. Manickchand-Heilemann, E. Martinez, and L. Vidal. 1999. Toward a stratified mass-balance model of trophic fluxes in the Gulf of Mexico large marine ecosystem. In H. Kumpf, K. Steidinger, and K. Sherman (Editors), *The Gulf of Mexico Large Marine Ecosystem*, p. 78–293. Blackwell Sci., Inc., Malden, Mass.
- _____, V. Christensen, S. Guenette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. *Nature* 418:689–695.
- _____, J. Alder, E. Bennett, V. Christensen, P. Tyedmers, and R. Watson. 2003. The future for fisheries. *Science* 302:1359–1361.
- _____, R. Watson, and J. Alder. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Trans. R. Soc. Lond. B: Biol. Sci.* 360(1453):5–12.
- Peterson, C. H., M. C. Kennicutt II, R. H. Green, P. Montagna, D. E. Harper, Jr., E. N. Powell, and P. F. Roscigno. 1996. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: a perspective on long-term exposures in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.* 53:2937–2954.

⁸U.S. Department of the Interior, Minerals Management Service, 2009b, Central Gulf of Mexico lease sale 208 attracts \$703,048,523 in high bids. News release, 18 March 2009 (online at <http://www.gomr.mms.gov/homepg/whatsnew/news-real/2009/090318.pdf>).

⁹NOAA expands fishing closed area in the Gulf of Mexico, 2010 (online at http://www.noaanews.noaa.gov/stories/2010/20100704_closure.html).

- Rabalais, N. N., R. E. Turner, and W. J. Wiseman, Jr. 1999. Hypoxia in the northern Gulf of Mexico: linkages with the Mississippi River. *In* H. Kumpf, K. Steidinger, and K. Sherman (Editors), *The Gulf of Mexico Large Marine Ecosystem*, p. 297–322. Blackwell Sci., Inc., Malden, Mass.
- _____, _____, and D. Scavia. 2002a. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River Nutrient policy development for the Mississippi River watershed reflects the accumulate scientific evidence that the increase in nitrogen loading is the primary factor in the worsening of hypoxia in the northern Gulf of Mexico. *BioScience* 52:129–142.
- _____, _____, Q. Dortch, D. Justic, V. J. Bierman, and W. J. Wiseman, Jr. 2002b. Nutrient-enhanced productivity in the northern Gulf of Mexico: past, present and future. *Hydrobiologia* 475/476:39–63.
- _____, _____, B. K. Sen Gupta, D. F. Boesch, P. Chapman, and M. C. Murrell. 2007. Hypoxia in the northern Gulf of Mexico: Does the science support the plan to reduce, mitigate and control hypoxia? *Estuarine Coasts* 30:753–772.
- Sammarco, P. W., A. D. Atchison, and G. S. Boland. 2004. Expansion of coral communities within the northern Gulf of Mexico via offshore oil and gas platforms. *Mar. Ecol. Prog. Ser.* 280:129–143.
- Shipp, R. L., and S. A. Bortone. 2009. A perspective of the importance of artificial habitat on the management of red snapper in the Gulf of Mexico. *Rev. Fish. Sci.* 17(1):41–47.
- Stanley, D. R., and C. A. Wilson. 2003. Seasonal and spatial variation in the biomass and size frequency distribution of fish associated with oil and gas platforms in the northern Gulf of Mexico. *Am. Fish. Soc. Symp.* 36:123–153.
- _____, and _____. 2004. Effect of hypoxia on the distribution of fishes associated with a petroleum platform off coastal Louisiana. *N. Am. J. Fish. Manage.* 24:662–671.
- Sullivan, C. L. 1985. *The Mississippi Gulf Coast: portrait of a people*. Windsor Publ., Northridge, Calif., 200 p.
- Swanton, J. R. 1979. *The Indians of the southeastern United States*. Smithsonian Inst. Press, Wash., D.C., 943 p.
- Watson, R., and D. Pauly. 2001. Systematic distortions in world fisheries catch trends. *Nature* 424:534–536.

Soft Flesh in Sablefish, *Anoplopoma fimbria*, of Southeastern Alaska: Relationships with Depth, Season, and Biochemistry

JOHN F. KARINEN, HAROLD J. BARNETT, and MICHELE MASUDA

Introduction

The quality of fish flesh is important to both commercial and sport fishermen. Soft flesh in fish may affect the yield, the success of preservation by freezing, the palatability, and the overall quality of the fish for market or consumption.

John F. Karinen is with the Auke Bay Laboratories, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Ted Stevens Marine Research Institute, 17109 Point Lena Loop Road, Juneau, AK 99801 and is the corresponding author (john.karinen@noaa.gov). Harold J. Barnett is with the Resource Enhancement and Utilization Technologies Division (REUT), Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112. Michele Masuda is with the Auke Bay Laboratories, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Ted Stevens Marine Research Institute, 17109 Point Lena Loop Road, Juneau, AK 99801.

The condition of "soft" flesh has been noted in several species of marine fish in the North Pacific, Gulf of Alaska, and the North Atlantic. The reasons for the occurrence of soft flesh has been determined for several fish species: parasite infestations (Levsen et al., 2008), spawning and cessation of feeding (Tomlinson et al., 1967), mineral accumulation (Teeny et al., 1984), temperature/exercise (Foy et al., 2006), biochemical adaptation to the deep sea (Siebenaller and Somero, 1989), and depth of occurrence (Norris et al.¹).

Sablefish or blackcod, *Anoplopoma fimbria*, a marine species of the shelf

and slope of the North Pacific Ocean, are found in commercial quantities from northern Mexico to Alaska and as far west as eastern Siberia (Kimura et al., 1998; Low et al.²). United States and Canadian fishermen have fished the North American resource for over a century, but it was not until the Japanese distant-water longline fishery developed in the 1960's that the resource was subject to intense exploitation (Low et al.²). The fishery did not fully develop on the U.S. west coast until the advent of the pot (trap) fishery developed by the Bureau of Commercial Fisheries (BCF) Biological Laboratory in Seattle, Wash.,

¹Norris, J. G., J. Rowley, and S. B. Mathews. 1987. Analysis of four factors affecting the sablefish soft fish problem. Contr. NA85-ABH00056, FRI-UW 8715, Fish. Res. Inst., Univ. Wash., Seattle. Final Rep. to Saltonstall/Kennedy Program, 55 p.

²Low, L. L., G. K. Tanonoka, and H. H. Shippen. 1976. Sablefish of the northeastern Pacific Ocean and Bering Sea. NWAFC Processed Rep., 115 p. Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, Wash.

ABSTRACT—The condition of soft-textured flesh in commercially harvested sablefish, *Anoplopoma fimbria*, from southeastern Alaska was investigated by National Marine Fisheries Service (NMFS) scientists from the Alaska Fisheries Science Center's Auke Bay Laboratories (ABL) in Alaska and the Northwest Fisheries Science Center in Seattle, Wash. Sablefish were sampled by longline, pot, and trawl at five sites around Chichagof Island at depths of 259–988 m in the summer of 1985 and at depths of 259–913 m in the winter of 1986. At the time of capture and data collection, sablefish were categorized as being "firm" or "soft" by visual and tactile examination, individually weighed, measured for length, and sexed. Subsamples of the fish were analyzed and linear regressions and analyses of variance were performed on both the summer ($n = 242$) and winter ($n = 439$) data for combinations of chemical and physical analyses, depth of

capture, weight vs. length, flesh condition, gonad condition, and sex.

We successfully identified and selected sablefish with firm- and soft-textured flesh by tactile and visual methods. Abundance of firm fish in catches varied by season: 67% in winter and 40% in summer. Winter catches may give a higher yield than summer catches. Abundance of firm fish catches also varied with depth. Firm fish were routinely found shallower than soft fish. The highest percentage of firm fish were found at depths less than 365 m in summer and at 365–730 m in winter, whereas soft fish were usually more abundant at depths greater than 731 m. Catches of firm fish declined with increasing depth. More than 80% of the fish caught during winter at depths between 365 and 730 m had firm flesh, but this declined to 48% at these depths in summer.

Longlines and pots caught similar proportions of firm and soft fish with both

gears catching more firm than soft fish. Trawls caught a higher proportion of soft fish compared to longlines and pots in winter.

Chemical composition of "firm" and "soft" fish differed. On average "soft" fish had 14% less protein, 12% more lipid, and 3% less ash than firm fish. Cooked yields from sablefish with soft-textured flesh were 31% less than cooked yields from firm fish.

Sablefish flesh quality (firmness) related significantly to the biochemistry of white muscle with respect to 11 variables. Summer fish of all flesh conditions averaged 6% heavier than winter fish. Regulating depth of fishing could increase the yield from catches, but the feasibility and benefits from this action will require further evaluation and study. Results of this study provide a basis for reducing the harvest of sablefish with soft flesh and may stimulate further research into the cause and effect relationship of the sablefish soft-flesh phenomenon.

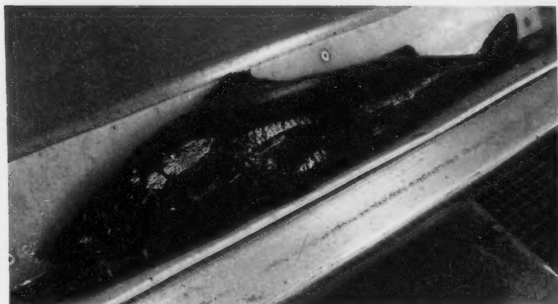


Figure 1.—Photo of a very black and soft-fleshed adult sablefish, taken July 2002 on the sablefish survey at a depth of 800 m.

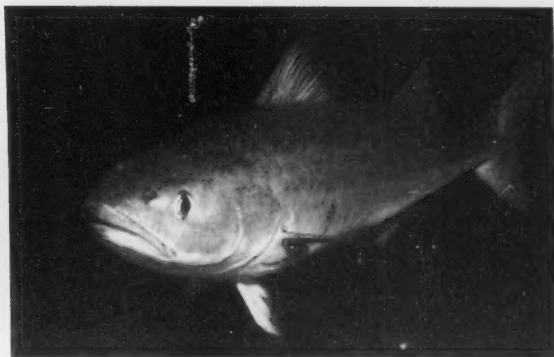


Figure 2.—Photo of a light colored firm-fleshed adult sablefish. Photo: Patrick Malecha, NOAA/NMFS Auke Bay Lab.

in the late 1960's (Hughes et al., 1970). It was then that the issue of sablefish with soft-textured flesh was noted by the commercial fishing industry and relayed to BCF fisheries personnel. Sablefish with "soft" flesh were first documented in deep-water samples taken during exploratory fishing activities in the mid 1960's off the coasts of Washington and Oregon, near the mouth of the Columbia River (Heyamoto and Alton, 1965).

Chemical analysis of sablefish, caught at depths ranging between 457 and 640 m in November and December of 1969, showed that the edible flesh of fish judged to be soft had an average water content of 81%, 10.1% fat content, and protein content of 6.7% (Patashnik et al.³). These data suggested that the increased water content and apparent protein depletion may be similar to a condition found in Dover sole, *Microstomus pacificus* (Patashnik and Groninger, 1964) and American plaice, *Hippoglossoides platessoides* (Templeman and Andrews, 1956) and may make these fish less suitable for processing. This condition was thought not to be unusual by Love (1970) who observed "the majority of fish experience severe (food) depletion for a part of every year of their lives and are therefore unusually adapted to mobi-

lizing their body constituents as a fuel for survival."

Follow-up research to the 1969 study was initiated by the National Marine Fisheries Service in 1971 and again in 1979 to further study the soft flesh problem as it concerned the emerging west coast pot fisheries for sablefish. The intent of that research was to examine possible methods for detecting and separating sablefish with soft flesh from "normal" sablefish that could be used by fishermen at sea or by fish processors at dockside. To accomplish this, it was necessary to acquire a better understanding of the nature of the problem. The studies included additional chemical analyses to reconfirm results of the earlier analyses, tests to determine the degree of softness or firmness by finger pressure or by specific gravity in brine, and tests to determine whether skin color was an indicator of softness. The results of these tests were related to depth of capture, which ranged between 457 and 823 m. Results from these studies (unpublished data) essentially confirmed what had been seen previously, that sablefish with high water content and low protein content generally were soft textured, and the incidence of this condition increased with depth of capture. The subjective methods to determine if fish were soft or firm when landed were evaluated during this period. A process using depth of catch and skin color of the fish was used in conjunction with finger pressure as a rapid method for separating soft

fish from firm fish at point of landing. It was also observed that sablefish caught deeper than 548 m tended to be larger, blacker or darker gray in color, sometimes with a rose-colored lateral tint, especially if spawned; these fish generally had soft-textured flesh (Fig. 1). Firm sablefish, caught shallower than 548 m and not spawned, were characteristically a green-gray color dorsally with a light gray or white underbelly (Fig. 2). These photos show the extremes of soft and firm sablefish. Soft fish ranged from very black on back and belly to black backs and dark grey bellies to dark grey backs and bellies.

Our study addressed the following questions:

- Does the occurrence of soft sablefish in Alaska waters relate to depth of capture, season, spawning condition, and type of fishing gear used?
- Do the results obtained in sablefish studies off Oregon and Washington apply to Alaska?
- Can the harvest of sablefish with soft-textured flesh be avoided by manipulating fishing seasons and fishing depths?

Specific objectives of our study were to 1) determine the effects of season, depth of capture, sex, sexual maturity, and gear type on flesh quality and 2) determine the relationships of water, protein, lipids, ash, and mineral content of muscle to flesh quality.

³Patashnik, M., H. Barnett, and J. Conrad. 1980. A preliminary report on soft sablefish from the pot fishery off the Washington Coast. Unpubl. rep., URD, Northw. Alaska Fish. Cent., NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, Wash.

Materials and Methods

Collection and Shipboard Processing

Sablefish were collected in south-eastern Alaska in the summer (June and August) of 1985 and winter (January and February) of 1986 at four locations in Chatham and Icy Straits and at one location offshore of Cape Cross (Fig. 3). Fish were captured with a 400-mesh otter trawl, longline (LL), and conical pots. Longlines were fished for 3 h, pots for 24 h, and the trawls for 0.5 h at depths ranging between 259 and 913 m. Depths of capture were recorded. Following capture, the fish were immediately sacrificed, weighed, bled, measured (fork length), and subjectively classified as soft or firm using the methods previously described, i.e.

finger pressure and skin color. They were then sexed, dressed, and classified as to gonad developmental stage. There are five stages of gonad development for each sex: 1) immature, 2) maturing juvenile, 3) mature, 4) spawning, and 5) post-spawning. Stomach fullness and contents were also noted but are not reported in this study. The cleaned fish were frozen and stored at -29°C for later objective and subjective testing. A total of 681 sablefish ($n = 242$ summer; $n = 439$ winter) were processed for the study. Data from all study sites were pooled.

Sample Preparation

In preparation for conducting thaw and cooked drip analyses, 25-mm thick steaks were removed by band saw from

just posterior to the pectoral fins of each frozen fish. The steaks were skinned and bones removed. Samples of nape meat were frozen at the time the fish were caught and prepared for chemical analysis by partially thawing the meats and then homogenizing them by passing them through a 4-mm perforated plate attached to a food grinder.

Chemical Analyses

Samples were stored frozen at -29°C until analyzed chemically. Analyses for water (moisture), lipids, total protein, and ash were determined according to official AOAC methods (Horowitz, 1980). Protein was determined by the Kjeldhal⁴ method and lipids were extracted using a soxhlet apparatus and methylene chloride solvent. Elemental (metal) analyses were made by atomic emission spectrometry as described by Teeny et al. (1984). Analyses were made for Na, K, Mg, Ca, P, Mn, Fe, Co, Cu, Sr, and Zn. Soluble protein was determined by the "salt extractable" nitrogen test or the modified Biuret method described by Snow (1950).

Thaw and Cooked Drip Analyses

To determine thaw and cooked drip loss, a steak sample from each fish was weighed and placed frozen in plastic, cook-in-the bag pouches with perforated bottoms that were in turn placed in slightly larger outer plastic bags. Half of the bags were weighted to ensure submersion of the sample during cooking. Samples were cooked in boiling water for 12 min. After removal from the boiling water, the samples in the inner bag were cooled and reweighed. Samples in the unweighted bags were suspended on racks and placed in a refrigerated cooler at 3°C and allowed to thaw for 24 h and reweighed after loss of water.

Data Analyses

Flesh condition—soft and firm—was tested for differences in total protein, lipid, gonad stage, pH, and yellow or yellow-green bile by capture depth

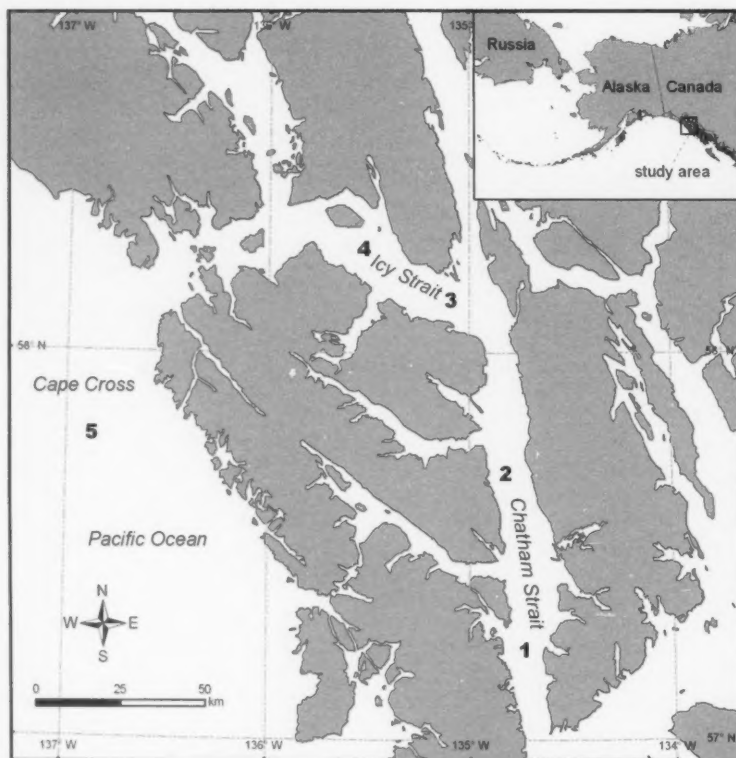


Figure 3.—Five general locations where sablefish were collected by longline, pots, or trawls: 1) near Kelp and Whitewater Bays, 2) near Tenakee, 3) Icy Strait—east entrance, 4) Icy Strait—Pleasant Island, and 5) Cape Cross. Specific locations (latitude and longitude), gear type, and catch information are available from the senior author. Trawling was done near sites 2–5 only.

⁴Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Numbers of sablefish classified as firm or soft in winter catches from Chatham and Icy Straits and Cross Sound, Southeast Alaska, and in summer catches from Chatham and Icy Straits, Southeast Alaska.

Season	Flesh condition	Males		Females	
		No.	(%)	No.	(%)
Winter	Firm	131	(74)	161	(61)
	Soft	45	(26)	102	(39)
	Total	176		263	
Summer	Firm	45	(39)	52	(41)
	Soft	70	(61)	75	(59)
	Total	115		127	

with separate multiple linear regression models. Yellow or yellow-green bile is indicative of well fed or recently fed fish while progressively darker green shades to dark blue indicates fish not recently fed (Robb, 1992). Flesh condition was treated as a dichotomous predictor (Weisberg, 1985) in the models with soft fish coded as 0 and firm fish coded as 1. For a fixed depth, the estimated regression coefficient for flesh condition can be interpreted as the estimated difference in the dependent variable for the two flesh conditions. Seventeen biochemical and chemical components of flesh samples were tested with one-way ANOVA's for differences between the two flesh conditions.

The components tested for differences between the soft and firm flesh include K, Mg, P, Zn, pH, total protein, Ca, Co Mn, Fe, Na, Cu, Sr, soluble protein, lipid, ash, and water. The α -level of significance (0.05) was adjusted with a Bonferroni correction for performing multiple comparisons. Various length-weight regressions by flesh condition, season, gender, and gonad condition were fit for graphical comparison. Condition factor, computed as $K = 10^4 \times W(g) / L^3(cm)$, was compared for flesh condition and by season with a two-way ANOVA. Only immature or developing fish (maturity stages 1 and 2) were included in the analysis.

The relative weight loss of soft- and firm-flesh fish samples was compared for thawed and cooked processing with one-way ANOVA's. Relative weight loss (%) of processed samples was calculated as $(\text{post-weight} - \text{pre-weight}) / \text{pre-weight} \times 100$. Analyses were performed separately for the summer and

Table 2.—Numbers of firm and soft sablefish captured by longline (LL) and pots in the summer and winter by depth and by trawl in the winter only. Percent firm fish by season, gear, and depth are indicated.

Season	Gear	Flesh condition	Depth (m)				
			259–364	365–547	548–730	731–913	914–988
Summer	LL	Firm	45 (76%)	29 (48%)	4 (17%)	1 (4%)	6 (75%)
		Soft	14	32	19	26	2
	Pot	Firm	11 (73%)	0 (0%)	0 (0%)	1 (5%)	
		Soft	4	0	27	21	
Winter	LL	Firm		68 (89%)	24 (100%)	8 (16%)	
		Soft		8	0	42	
	Pot	Firm		39 (87%)	50 (100%)	8 (15%)	
		Soft		6	0	45	
	LL+Pot	Firm		107 (88%)	74 (100%)	16 (16%)	
		Soft		14	0	87	
	Trawl	Firm	22 (100%)	33 (63%)	40 (60%)		
		Soft	0	19	27		

winter seasons. The tests were one-tailed as the soft flesh was hypothesized to lose more weight than firm flesh during thawing and cooking.

Results

Flesh Quality of Catch

By Season and Gender

More sablefish were subjectively classified as firm in the winter than in summer (Table 1). Firm males and females made up 67% of the winter catch (30% and 37%, respectively), but only 40% of the summer catch. The percentage of soft fish in the summer catch (61% males, 59% females) was, respectively, 2.3 and 1.5 times that seen in the winter. Soft females and males were about equally abundant in the summer landings, 59% and 61%, respectively, but soft females exceeded soft males in the winter catch (39% vs. 26%).

By Gear, Depth, and Season

Gear selectivity for flesh condition varied with type of gear and depth (Table 2). At the shallowest depth fished in summer (259–364 m) about three times more fish were designated firm than soft in catches from both longline and pot gear. At depths 365–547 m nearly equal numbers of firm and soft fish were taken by longline gear in the summer. At depths 548–913 m most fish were soft in longline and pot catches.

Catches in the winter with longlines and pots showed a similar trend but started deeper; at 365–547 m and 548–730 m most fish were firm while most fish were soft at 731–913 m.

Trawls caught more firm fish than soft fish at all depths. In contrast, flesh quality composition of trawl catches was much different than the composition of combined longline and pot catches at the same depths in winter (Table 2). The proportion of firm fish in trawl catches was, respectively, 25% and 40% lower than pots and longline at depth intervals of 365–547 m and 548–730 m. No trawling was done in summer.

Catches of firm-fleshed sablefish on longlines and in pots declined with increasing depth in winter and summer (Table 2). Most of the fish caught in summer at depths shallower than 365 m were firm, but fish were increasingly soft-textured when caught at depths greater than 547 m. Most winter-caught fish (> 80%) were firm at depths in the shallow interval (365–547 m) and the middle interval (548–730 m). In both summer and winter the percentage of firm fish caught was low (4–16%) in the depth interval 731–913 m.

Sexual Maturation and Flesh Quality

Winter catches by gonad stage and quality of flesh were summed over depths and compared for longline plus pots (LL+POT) and trawl catches (Table 3). Most fish were gonad stage 1 or 2 (immature or developing), but a few were stage 3, 4, or 5 (gravid, ripe, or spent). The percentages of firm and soft fish of both sexes were similar and nearly overlapping for all three gear types. Spent females appear only in the soft category. Also, a greater percentage of maturity stages 3, 4, and 5 occurred

among the soft fish compared to firm fish, especially for trawl catches.

Fish Condition by Season

Length-weight regressions for male fish judged to be firm or soft in flesh texture indicate that summer fish were generally heavier than winter fish of the same fork length. Fit for most of these regressions is good with R^2 values ranging from 0.76 to 0.91 (Table 4). Figure 4 shows the winter and summer maturity regressions for firm males. Firm summer males of 54 to 66 cm fork length (line 2) appear to be heavier than firm winter males of similar length (line 1). Gonad development further explains the differences in weight between firm males (Fig. 5). As gonads develop through stages 1–4, they account for an increasing proportion of weight to the overall mass of the fish. Length-weight regressions for firm and soft, winter and summer females (Fig. 6) show a similar

length-weight relationship with respect to maturity stage but the slopes for the various gonad stages (Fig. 7) are different than the males.

To eliminate the influence of gonad weight on the summer and winter comparison of fish, we calculated the condition factor (K) for all fish that were immature or developing (maturity stages 1 and 2). The formula for the condition factor is $K = 10^4 \times W(g) / L^3(cm)$. Gonad weights in these fish would be less than other maturity stages. A two-way analysis of variance on condition factor (K) classified by season and flesh condition was calculated for these fish.

No evidence of interaction between season and flesh (ANOVA, $F = 1.16 \sim F_{1,577}$, $P = 0.28$) or a significant difference in flesh condition (ANOVA, $F = 0.54 \sim F_{1,577}$, $P = 0.46$) was seen but the seasonal difference was significant (ANOVA, $F = 1.16 \sim F_{1,577}$, $P = 0.02$). The summer fish had a higher mean

condition factor (108.5, $SE = 1.45$) than the winter fish (104.6, $SE = 0.70$). Assuming that sablefish of all gonad developmental stages would show this difference in condition factor, we could expect fish caught in the summer to be about 3% heavier than fish caught in the winter.

Winter and summer differences in body weight were further examined by comparing the average weight of winter and summer fish (combined males and females) by length intervals (Table 5). These data show that mean weights of winter and summer caught fish differed by size groups. Small fish (< 58 cm) were 15% heavier in summer than in winter, but differences between other size groups varied from -2 to +9%. Overall, fish caught during the summer averaged 6% heavier than fish caught during the winter. We believe that gonad weights influenced the comparison of larger fish, winter versus summer, and therefore the 6% difference between mean weights of winter and summer fish is a minimum estimate. These data indicate that summer fish are clearly heavier than winter fish of the same length.

Depth of Capture vs. Proximate Analyses, Flesh Condition, and Gonad Stage

The relationships of total protein, lipid, gonad stage, pH, and green bile to depth of capture were complex and inconsistent (Table 6). Total protein, lipid, and green bile were related to flesh condition and depth of capture. Gonad

Table 3.—Numbers of sablefish with firm and soft flesh condition by gonad development caught in winter with longlines (LL) and pots versus trawls. Catches are summed over all depths and percentages by gonad stage are given in parentheses.

Gear	Gender	Flesh condition	Number by Gonad Stage ¹ (%)					Total
			1	2	3	4	5	
LL+Pot	Male	Firm	55 (68)	16 (20)	1 (1)	0 (11)	0 (0)	81
		Soft	17 (68)	4 (16)	0 (0)	4 (16)	0 (0)	25
	Female	Firm	8 (7)	92 (79)	5 (4)	11 (9)	0 (0)	116
		Soft	0 (0)	48 (63)	6 (8)	11 (14)	11 (14)	76
Trawl	Male	Firm	14 (28)	33 (66)	3 (6)	0 (0)	0 (0)	50
		Soft	2 (10)	12 (60)	2 (10)	4 (20)	0 (0)	20
	Female	Firm	4 (9)	37 (82)	1 (2)	3 (7)	0 (0)	45
		Soft	0 (0)	11 (42)	1 (4)	12 (46)	2 (8)	26

¹ Maturity code: 1) immature, 2) maturing juvenile, 3) mature, 4) spawning, and 5) spent or post-spawning.

Table 4.—Fitted regressions of sablefish weight (Y) on length (X), associated figures, and summary statistics: residual degrees of freedom (d.f.), estimated standard error of regression ($\hat{\sigma}$), multiple correlation coefficient (R^2), the F statistic, and the p -value for the model (P). Gender, season, flesh condition, gonad stage, and fork length (cm) of samples are provided for each fitted regression line.

Figure	Gender	Season	Flesh condition	Gonad stage	Fork length (cm) range	Equation	d.f.	$\hat{\sigma}$	R^2	F	P
4, line 1	Male	Winter	Firm	All	37–68	$Y = -8.45 + 0.23 X$	129	0.52	0.86	778.5	< 0.001
4, line 2	Male	Summer	Firm	All	54–67	$Y = -13.26 + 0.31 X$	16	0.47	0.85	88.0	< 0.001
4, line 3	Male	Winter	Soft	All	51–70	$Y = -9.42 + 0.24 X$	43	0.35	0.90	389.1	< 0.001
4, line 4	Male	Summer	Soft	All	54–72	$Y = -8.89 + 0.24 X$	50	1.04	0.48	46.6	< 0.001
5, line 1	Male	Winter	Firm	1	37–68	$Y = -6.69 + 0.19 X$	67	0.37	0.90	580.9	< 0.001
5, line 2	Male	Winter	Firm	2	49–64	$Y = -10.85 + 0.27 X$	47	0.61	0.76	151.3	< 0.001
5, line 4	Male	Winter	Firm	4	55–68	$Y = -9.13 + 0.25 X$	7	0.43	0.87	48.2	< 0.001
6, line 1	Female	Winter	Firm	All	39–85	$Y = -11.06 + 0.27 X$	159	0.70	0.91	1653.0	< 0.001
6, line 2	Female	Summer	Firm	All	45–70	$Y = -10.11 + 0.26 X$	15	0.47	0.90	140.5	< 0.001
6, line 3	Female	Winter	Soft	All	48–93	$Y = -17.61 + 0.38 X$	100	1.26	0.90	927.8	< 0.001
6, line 4	Female	Summer	Soft	All	52–84	$Y = -10.33 + 0.26 X$	53	1.37	0.77	181.1	< 0.001
7, line 2	Female	Winter	Soft	2	47–78	$Y = -12.00 + 0.29 X$	57	0.77	0.86	349.4	< 0.001
7, line 4	Female	Winter	Soft	4	68–96	$Y = -29.18 + 0.53 X$	21	1.21	0.91	202.7	< 0.001
7, line 5	Female	Winter	Soft	5	65–93	$Y = -22.40 + 0.43 X$	11	1.75	0.81	45.7	< 0.001

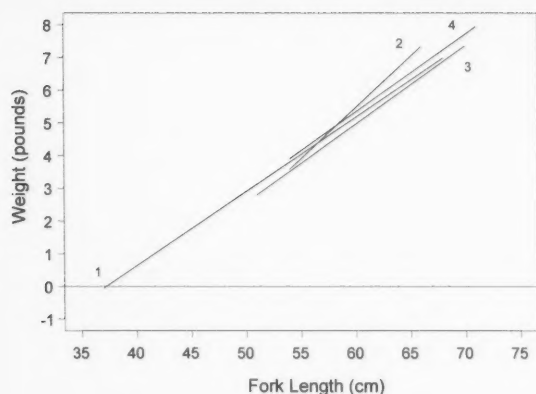


Figure 4.—Length-weight regressions for male sablefish: 1) firm winter, 2) firm summer, 3) soft winter, and 4) soft summer. See Table 4 for data on lines 1–4.

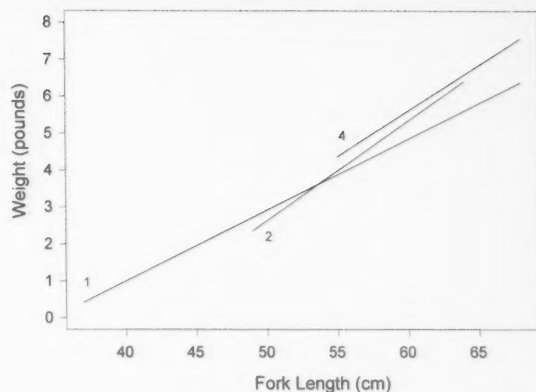


Figure 5.—Length-weight regressions for firm winter male sablefish by gonad stages 1, 2, and 4. See Table 4 for data on lines 1, 2, and 4.

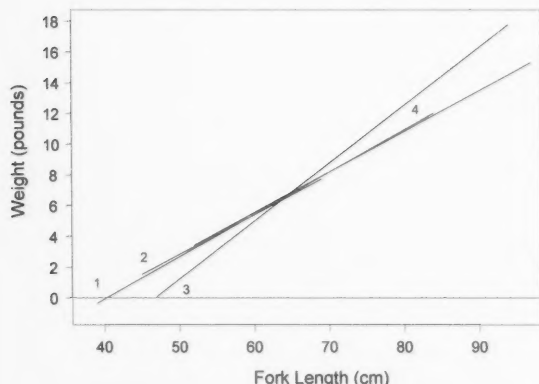


Figure 6.—Length-weight regressions for 1) firm winter, 2) firm summer, 3) soft winter, and 4) soft summer female sablefish. See Table 4 for data on lines 1–4.

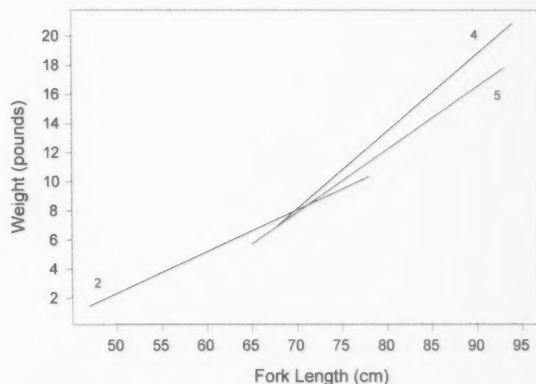


Figure 7.—Length-weight regressions for soft winter female sablefish by gonad stages 2, 4, and 5. See Table 4 for data on lines 2, 4, and 5.

development was related to depth of capture but only marginally related to flesh condition. Conversely, flesh pH was related to flesh condition but not to depth of capture.

Proximate Composition and Electrolyte Analyses and Flesh Condition

Among 17 variables (including protein, lipid, and pH previously mentioned) that we examined in sablefish flesh, 11 showed significant differences between firm and soft fish (Table 7). Variables for which the means were

Table 5.—Average weight (g), sample sizes (*n*), and percent difference in weight by length interval for combined male and female sablefish in winter and summer. Only sablefish of maturity stages 1 and 2 were included. The average percent difference in weight was 6%.

	Length interval (cm)					
	< 58	58–60	60–63	63–66	66–69	69–97
Weight	1,525	2,104	2,444	2,881	3,253	3,979
<i>n</i>	173	38	54	37	30	21
Summer	1,749	2,135	2,636	2,931	3,195	4,354
<i>n</i>	16	18	34	21	20	33
% difference	15	2	8	2	-2	9

higher for soft fish compared to firm fish included lipid, water, and the electrolytes sodium (Na) and strontium (Sr). All other means were lower for the soft

fish. Higher sodium and lower potassium (K) in white muscle of fish are usually indicative of starvation (Love, 1980). Similar differences in sodium

Table 6.—Summary statistics for the multiple linear regressions of total protein, lipid, gonad stage, pH, and green bile on flesh condition (soft coded as 0 and firm coded as 1) and depth of capture. Summary statistics are the estimated regression coefficients (Coefficient), the standard error of the estimate (SE), the *t*-statistic (*t*), and the marginal *p*-value (*P*). Also reported are the estimated standard error of regression ($\hat{\sigma}$), multiple correlation coefficient (R^2), the *F* statistic and associated degrees of freedom, and the *p*-value (*P*).

Variable	Coefficient	SE	<i>t</i>	<i>P</i>
Total Protein				
Intercept	132.79	4.36	30.4	< 0.001
Flesh condition	12.75	2.60	4.9	< 0.001
Depth	-0.02	0.01	-3.5	< 0.001
$\hat{\sigma} = 12.8$; multiple $R^2 = 0.36$; $F_{2, 176} = 49.7$; $P < 0.001$				
Lipid				
Intercept	192.11	15.25	12.6	< 0.001
Flesh condition	-33.08	9.09	-3.6	< 0.001
Depth	-0.06	0.02	-3.0	0.003
$\hat{\sigma} = 44.5$; multiple $R^2 = 0.07$; $F_{2, 176} = 7.0$; $P = 0.001$				
Gonad				
Intercept	1.06	0.29	3.7	< 0.001
Flesh condition	0.25	0.17	1.5	0.14
Depth	1.6e-3	3.7e-4	4.2	< 0.001
$\hat{\sigma} = 0.8$; multiple $R^2 = 0.10$; $F_{2, 176} = 10.2$; $P < 0.001$				
pH				
Intercept	6.74	0.06	119.1	< 0.001
Flesh condition	0.18	0.03	5.4	< 0.001
Depth	-4.1e-5	7.4e-5	-0.6	0.58
$\hat{\sigma} = 0.2$; multiple $R^2 = 0.24$; $F_{2, 176} = 28.1$; $P < 0.001$				
Green bile				
Intercept	-6.25	1.16	-5.4	< 0.001
Flesh condition	5.71	0.69	8.2	< 0.001
Depth	0.01	1.5e-3	8.2	< 0.001
$\hat{\sigma} = 3.4$; multiple $R^2 = 0.32$; $F_{2, 176} = 41.1$; $P < 0.001$				

Table 7.—Means, standard deviations (S.D.), and probabilities (*P*) for the ANOVA models for firm (*n* = 64) and soft (*n* = 115) sablefish tested for differences among 17 biochemical variables.

Variable ¹	Flesh condition		<i>P</i>
	Firm	Soft	
	Mean (S.D.)	Mean (S.D.)	
K	3669.8 (461.7)	3351.5 (252.4)	< 0.001 ²
Mg	260.1 (28.5)	215.1 (23.1)	< 0.001 ²
P	1928.9 (150.4)	1700.8 (116.1)	< 0.001 ²
Zn	3.1 (0.6)	2.5 (0.4)	< 0.001 ²
pH	6.9 (0.1)	6.7 (0.2)	< 0.001 ²
Protein (Total)	136.8 (12.0)	118.2 (13.8)	< 0.001 ²
Ca	60.9 (21.6)	49.1 (17.7)	< 0.001 ²
Co	0.02 (0.02)	0.01 (0.007)	< 0.001 ²
Mn	0.08 (0.07)	0.05 (0.03)	< 0.001 ²
Fe	4.6 (4.2)	3.0 (1.3)	< 0.001 ²
Na	494.1 (95.2)	595.9 (206.3)	< 0.001 ²
Cu	0.25 (0.09)	0.21 (0.1)	0.01
Sr	0.22 (0.11)	0.26 (0.1)	0.02
Protein (Soluble)	64.3 (8.9)	60.5 (11.2)	0.02
Lipid	132.6 (53.4)	148.1 (40.6)	0.03
Ash	10.6 (1.1)	10.3 (0.9)	0.04
Water	720.7 (49.0)	726.1 (48.4)	0.48

¹ Protein, lipid, ash, and water are in units of mg/g; all others except pH are in units of μ g/g.

² Significant test with $\alpha = 0.05$ and a Bonferroni correction of 1/17.

Table 8.—Means, standard errors of the means (SE), and sample sizes (*n*) for the relative drip and cook drip loss (%) of the winter and summer samples. Relative weight loss (%) is calculated as (post-weight-pre-weight) / pre-weight $\times 100$.

	Winter						Summer					
	Firm			Soft			Firm			Soft		
	Mean	SE	<i>n</i>	Mean	SE	<i>n</i>	Mean	SE	<i>n</i>	Mean	SE	<i>n</i>
Thaw	5.6	0.41	93	14.6	0.68	138	8.3	0.80	33	6.7	0.64	84
Cook	21.7	0.70	94	29.8	0.44	128	18.9	1.43	36	24.0	0.89	84

and potassium have also been observed in spawning salmon (Tomlinson et al., 1967). In laboratory studies, Sullivan and Somero (1983) were able to induce physiological changes in starved sablefish that closely resemble the biochemical and physical characteristics of soft fish that we observed in the research reported here.

Differences in mean chemical constituents in soft compared to firm fish were as follows: protein was lower by 14% from 137 mg/g to 118 mg/g, water was higher by 1% from 721 mg/g to 726 mg/g (but not significantly), lipid was higher by 12% from 133 mg/g to 148 mg/g, and ash was lower by 3% (Table 7).

Yield Analysis

Changes in weight of winter and summer samples during the processes of thawing and cooking are shown in Table 8. Soft sablefish lost 45% more thaw drip loss in 24 h and 24% more cooked drip loss than the firm sablefish. Average weight loss in the thaw drip loss test was 6% for the firm fish and 12% for soft fish. In the cooked drip loss test, average losses for firm- and soft-textured fish were 21% and 27%, respectively.

Yield differed in winter and summer by flesh quality, but not consistently. Thaw drip loss for soft fish in winter was more than twice that of summer caught fish (14.6% vs. 6.7%). Thaw drip loss for firm fish averaged 8.3% in summer and 5.6% in winter.

Differences in cooked drip loss in winter and summer were not great between firm and soft fish. Cooked drip loss for firm fish in winter averaged 21.7%, while soft fish averaged 29.8%. In summer the cooked drip loss was 18.9% for firm fish and 24.0% for soft fish.

The relative weight loss of the soft-flesh samples in winter was significantly higher than the firm-flesh samples for both the thawed (ANOVA, $F = 99.0 \sim F_{1, 229}$, $P < 0.001$) and cooked samples (ANOVA, $F = 106.1 \sim F_{1, 220}$, $P < 0.001$) (Table 8, Fig. 8). The relative weight loss of the summer, thawed samples was not significantly higher for the

soft-flesh samples than for the firm-flesh samples (ANOVA, $F = 2.0 \sim F_{1,115}$, $P = 0.16$) (Fig. 9a); however, the soft-flesh samples lost significantly more relative weight during the cooking process (ANOVA, $F = 9.3 \sim F_{1,118}$, $P = 0.003$) (Fig. 9b).

Discussion

Biological, Physiological, and Environmental Factors

Several factors may be contributing to the observed incidence of soft flesh in sablefish: reproductive cycle, distribution of fish over a greater depth range as they mature and grow, changes in diet as they move deeper in the water column, and physiological changes induced by increased pressure. We have noted soft flesh in sablefish after spawning but have not determined whether spawning itself or their presence at great depth (> 300 m) contributes to the incidence of soft flesh. Most of the soft fish are dark black in color, and their size range extends from small, recently-maturing fish to very large females that have spawned several times. This suggests that depth of occurrence may have a major influence on the development of soft flesh but the reproductive cycle may exacerbate its development. We need to examine available tag data reports on soft female sablefish to determine if individual fish remain soft following spawning at great depth.

Effects of Time and Depth of Fishing and Gear Type on Catch Composition and Yield

Results of our study indicate that regulating time of fishing, depth of fishing, and gear type may increase the number of firm sablefish in catches. Yield from soft fish is considerably less than from firm fish (this study; Norris et al.¹; Patashnik et al.³); therefore, it is important to optimize the catch of firm fish. Yield is also dependent upon the condition factor of the fish or weight per given length. Our study shows that summer fish of all flesh conditions are on average 6% heavier than winter fish; therefore, yield from summer fish would be expected to be higher. Summer

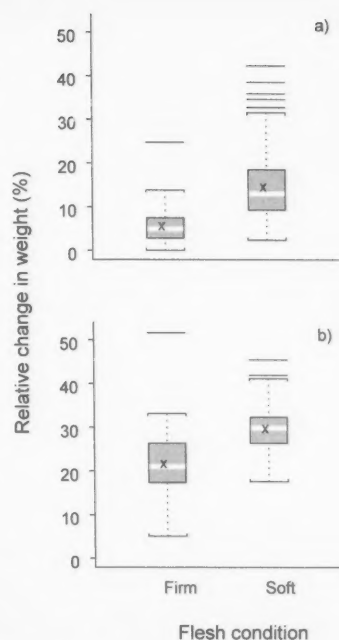


Figure 8.—Boxplots of relative change in weight (%) for a) thawed and b) cooked winter samples by flesh condition. The mean is indicated by X.

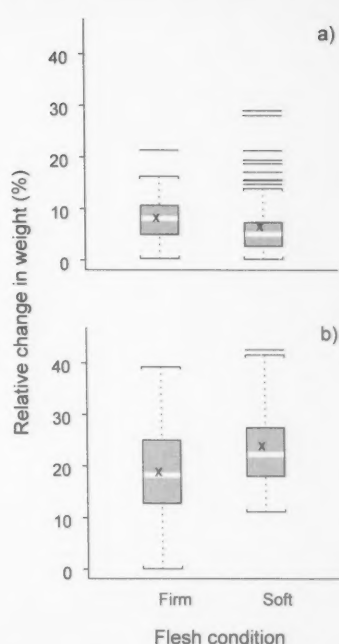


Figure 9.—Boxplots of relative change in weight (%) for a) thawed and b) cooked summer samples by flesh condition. The mean is indicated by X.

catches of sablefish, however, have 27% more soft-fleshed fish, which would reduce their overall yield.

If fishing were in late summer, would the increased yield from heavier fish offset the loss from soft fish? Probably not, because loss of yield from soft sablefish is considerable: 45% greater thaw drip loss from thawed raw fillets and 24% greater cooked drip loss. Although not measured here, there is also a loss of quality associated with the loss of drip in that nutrients such as protein, nitrogen, essential electrolytes, and other flavor components are removed with the drip (Miyauchi and Spinelli, 1967). Storage temperature could also significantly affect the composition and amount of drip produced in soft-textured sablefish. Storage temperatures of -20°C , commonly used in commercial cold storage facilities, would be expected to produce a higher thaw and cooked drip loss than storage at -30°C (Miyauchi, 1963).

The numbers of sablefish with soft flesh are probably of more importance to overall yield than small differences in physical conditions. A detailed calculation of overall yields from summer and winter catches is beyond the scope of this paper, but based on available information, winter catches would probably produce higher yields. Fishing all depths in winter (Jan.–Feb.) would yield a catch consisting of 67% firm fish, whereas the summer catch (June–Aug.) would yield only 40% firm fish. Presently the season in Chatham Strait is from 15 Aug. to 15 Nov. We have no information on the composition of the catch regarding flesh condition from this area from September to November but expect it would be between 40% and 60% firm fish over all fishing depths. Based on the results of our research, it appears that the commercial season in Chatham Strait may already be at the optimum time.

Regulating the depth of fishing also has the potential for increasing the yield

from sablefish landings. Depth distribution of sablefish changes by season; however, all appeared to move deeper in winter. Firm fish were located at shallower depths (< 365 m) in summer but appeared to be located in deeper water (< 548 m) in the winter. Soft fish also appeared to be in deeper water in the winter from 548 to 730 m or more. Limiting fishing to depths where soft fish are less abundant may increase yield from the catch and reduce waste of soft fish. If fishing were limited to less than 731 m in winter, the catch would produce about 82% firm fish.

How much this would affect the overall catch is not clear; 23% of the winter catch in our study was from depths greater than 730 m. If, on the other hand, fishing in the summer were limited to less than 548 m, the catch would yield about 63% firm fish. However, the overall catch may be reduced because 44% of the summer catch in our study came from depths greater than 547 m. Catches from depths greater than 730 m have more large fish in winter and summer; therefore, the average weight of fish would probably be less if the above depth changes were adopted.

How changes in fishing depth and season would affect the offshore fishery is not clear. Presently, the sablefish fisheries in both the Gulf of Alaska and the Bering Sea use fixed gear (longlines and pots) under Individual Fishing Quota (IFQ) programs. The fixed gear seasons open 15 Mar. and close 15 Nov. Only one of our study sites (Cross Sound) was in offshore waters. Distribution of firm- and soft-textured fish by depth at this site was similar to the Chatham Strait sites, so perhaps our study results could be applied.

Whether regulating fishing depth is feasible and beneficial to yield depends upon several factors: 1) the present depth distribution of fishing effort, 2) the area of depth strata available, and 3) the distribution of fish by depth. Clearly more information is needed before one can determine the impact of depth regulations on yield.

The effect of gear selectivity for soft fish seems clear. Longlines and pots took similar proportions of soft fish in

both summer and winter. Trawl catches contained a higher proportion of soft fish compared to longlines and pots, perhaps because soft fish may be less attracted to bait and are, therefore, less available to longlines and pots. Trawls would take them regardless of feeding behavior.

Relationship of Biochemistry to Soft Flesh

Biochemistry of sablefish flesh differs from soft to firm. A better understanding of the cause-effect relationship of the soft flesh problem would help us predict its distribution in time and location. Differences in flesh quality may be the result of genetic variability or the prolonged exposure to different environmental factors associated with depth as hypothesized in previous studies (Norris et al.¹). Food availability, food quality, activity level, temperature, and pressure are all factors associated with depth, which could change the physiology and biochemistry of sablefish. Sablefish (Sullivan and Smith, 1982) and many other mesopelagic and bathypelagic fishes living at great depths (Siebenaller and Somero, 1989; Drazen, 2007) have been shown to have higher water content and lower protein and lipid content than species living at shallow depths. Deepwater species adapt biochemically by lowering metabolic and enzyme rates to conserve energy and change physiological processes by reducing locomotory activity in response to living in an environment where food resources are sparse and meals infrequent (Drazen, 2007). Metabolic rates of vertically migrating mesopelagic fish decreased with increase in depth of occurrence (Karinen, 1965), but the duration of time at depth necessary to initiate biochemical changes has not yet been established. Foy et al. (2006) investigated the roles of temperature, pH, and exercise in the development of "chalkiness" in Pacific halibut, *Hippoglossus stenolepis*, but were not able to reproduce the effects in halibut held and exercised to exhaustion in a laboratory experiment. Reproductive development may also influence the biochemical composition of fish flesh as shown by our data.

Results of our study seem contradictory with respect to determining the cause of soft flesh in sablefish. Is it diet, parasites, depth of occurrence, life stage, or genetics? High sodium, low potassium, and yellow to yellow-green bile in soft fish are all indicative of well-fed fish (McCormick and Podoliak, 1984). Parasites can cause soft flesh; myxosporean parasites are known to cause soft flesh in Atlantic mackerel, *Scomber scombrus* (Levensen et al., 2008). Some species of these parasites are known to be present in the North Pacific but it is unlikely that such parasites were present in our study because cysts (black or white) in the flesh can usually be seen with the naked eye and the flesh liquefies when cooked. Perhaps one way to answer the question of cause and effect would be to determine the genetic types and variability of firm and soft sablefish (Tsuyuki and Roberts, 1969).

Acknowledgments

We wish to thank the following for their help in this study: Alice S. Hall, Adam Moles, Jerome Pella, Joanne Hudson, Nancy Maloney, Tom Rutecki, Mike Sigler, and the crew and fisheries personnel of the NOAA ships *John N. Cobb* and *Miller Freeman*.

Literature Cited

- Drazen, J. C. 2007. Depth related trends in proximate composition of demersal fishes in the eastern North Pacific. *Deep-Sea Res. Pt. I: Ocean. Res. Pap.* 54(2):203–219.
- Foy, R. J., C. A. Crapo, and D. E. Kramer. 2006. Investigating the roles of temperature and exercise in the development of chalkiness in Pacific halibut. *Int. Pac. Halibut Comm., Seattle, Tech. Rep.* 50, p. 1–24.
- Heyamoto, H., and M. S. Alton. 1965. Distribution, abundance, and size of sablefish (*Anoplopoma fimbria*) found in deep water off the Columbia River. *Commer. Fish. Rev.* 27(11):1–8.
- Horowitz, W. 1980. Official methods of analysis of the Association of Official Chemists, 13th ed. AOACS, Wash., D.C.
- Hughes, S. E., D. D. Worlund, and F. W. Hopkins. 1970. Adaptation of king crab pots for capturing sablefish (*Anoplopoma fimbria*). *J. Fish. Res. Board Can.* 27(10):1747–1755.
- Karinen, J. F. 1965. Succinic dehydrogenase activity in mesopelagic oceanic fishes. Master's Thesis, Oreg. State Univ., Corvallis, 71 p.
- Kimura, D. K., A. M. Shimada, and F. R. Shaw. 1998. Stock structure and movement of tagged sablefish, *Anoplopoma fimbria*, in offshore northeast Pacific waters and the effects

- of El Niño-Southern Oscillation on migration and growth. *Fish. Bull.* 96:462-481.
- Levsen, A., A. Jorgensen, and T. A. Mo. 2008. Occurrence of postmortem myoliquefactive kudoosis in Atlantic mackerel, *Scomber scombrus* L., from the North Sea. *J. Fish Dis.* 31(8):601-611.
- Love, R. M. 1970. Depletion. In *The chemical biology of fishes*, chapt. 5. Acad. Press, N.Y.
- . 1980. *The chemical biology of fishes*, vol. 2. Acad. Press, Lond., 943 p.
- McCormick, J. H., and H. A. Podoliak. 1984. Gallbladder color and relative fullness as a field technique for estimating time since last feeding in brook trout. *N. Am. J. Fish. Manage.* 4:566-568.
- Miyauchi, D. T. 1963. Drip formation in fish. 1.—a review of factors affecting drip. *Fish. Ind. Res.* 2(2):13-20.
- and J. Spinelli. 1967. Drip formation in fish 3—composition of drip from defrosted Pacific cod filets. *Fish. Ind. Res.* 2(4):61-65.
- Patashnik, M., and H. S. Groninger. 1964. Observations on the milky condition in some Pacific coast fishes. *J. Fish. Res. Board Can.* 21(2):335-346.
- Robb, A. P. 1992. Changes in the gall bladder of whiting (*Merlangius merlangus*) in relation to recent feeding history. *ICES J. Mar. Sci.* 49(4):431-436.
- Siebenaller, J. F., and G. N. Somero. 1989. Biochemical adaptation to the deep sea. *Rev. Aquat. Sci.* 1(1):1-25.
- Snow, J. M. 1950. Proteins in fish muscle. II. Colorimetric estimation of fish muscle protein. *J. Fish. Res. Board Can.* 7(10):594-598.
- Sullivan, K. M., and K. L. Smith Jr. 1982. Energetics of sablefish, *Anoplopoma fimbria*, under laboratory conditions. *Can. J. Fish. Aquat. Sci.* 39(7):1012-1020.
- and G. N. Somero. 1983. Size and diet-related variation in enzymic activity and tissue composition in sablefish, *Anoplopoma fimbria*. *Biol. Bull.* 164:315-326.
- Teeny, F. M., E. J. Gauglitz, Jr., A. S. Hall, and C. R. Houle. 1984. Mineral composition of the muscle tissue of seven species of fish from the Northeast Pacific. *J. Agric. Food Chem.* 32(4):852-855.
- Templeman, W., and G. L. Andrews. 1956. Jelly condition in the American plaice *Hippoglossoides platessoides* (Fabricius). *J. Fish. Res. Board Can.* 13(2):147-182.
- Tomlinson, N., J. R. McBride, and S. E. Geiger. 1967. The sodium, potassium, and water content of the flesh of sockeye salmon (*Oncorhynchus nerka*) in relation to sexual development and starvation. *Fish. Res. Board Can.* 24(2):243-248.
- Tsuyuki, H., and E. Roberts. 1969. Muscle protein polymorphism of sablefish from the Eastern Pacific Ocean. *J. Fish. Res. Board Can.* 26(10):2633-2644.
- Weisberg, S. 1985. *Applied linear regression*. John Wiley & Sons, N.Y., 324 p.

Authors, Titles, and Subjects in the *Marine Fisheries Review* 72(1-4), 2010

A

- Abbott-Jamieson, Susan, and Patricia M. Clay, "The long voyage to including sociocultural analysis in NOAA's National Marine Fisheries Service," 2: 14-33
- Abralia redfieldi*
deep-water bottom trawl survey, 4:20-25
- Aetobatis narinari*—see Ray, spotted eagle
- Allen, Mike S.—see Morgan et al.
- Amusium papyraceum*—see Scallop, paper
- Anasimus latus*—see Crab, stilt spider
- Anoplopoma fimbria*—see Sablefish

B

- Balaenoptera acutorostrata*—see Whale, minke
- Balaenoptera musculus*—see Whale, blue
- Barnett, Harold J.—see Karinen et al.
- Barracuda, great
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- "The black clam, *Villorita cyprinoides*, fishery in the State of Kerala, India," by N. Suja and K. S. Mohamed, 3:48-61
- Bobtail, greater shining
deep-water bottom trawl survey, 4:20-25
- Bonnethead
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- Burgess, George—see Morgan et al.
- Butterfish, gulf
deep-water bottom trawl survey, 4:20-25
- Bycatch
bottom longline shark fishery, 2002-06, 2:34-38
platform terminal transmitters/TED interactions, 3:44-47

C

- Caillouet, Ch. rles W., Jr.—see Nance et al.
- Calappa sulcata*—see Crab, yellow box
- Carcharhinus acronotus*—see Shark, black-nose
- Carcharhinus brevipinna*—see Shark, spinner
- Carcharhinus falciformis*—see Shark, silky
- Carcharhinus leucas*—see Shark, bull
- Carcharhinus limbatus*—see Shark, black-tip

- Carcharhinus obscurus*—see Shark, dusky
- Carcharhinus perezi*—see Shark, Caribbean reef
- Carcharhinus plumbeus*—see Shark, sandbar
- Carcharhinus signatus*—see Shark, night
- Carcharias taurus*—see Shark, sand tiger
- Caretta caretta*—see Sea turtle, loggerhead
- Carlson, John—see Morgan et al.
- Catch, historical
gray whale
Baja California shore stations, 1:1-25
California shore stations, 1:1-25
eastern North Pacific, ship-based, 1:26-65
humpback whale
Baja California shore stations, 1:1-25
California shore stations, 1:1-25
North Atlantic Ocean, 3:1-43
- Clam, black
biology, 3:51
ecology, 3:51
fishermen, 3:51-52
fishery, 3:52-53
fishing methods, 3:53-55
habitat, 3:48-51
marketing
cooked meats, 3:56-57
shells, 3:57-58
processing, 3:55-56
shell mining, 3:58-59

- Clay, Patricia M.—see Abbott-Jamieson and Clay
- Cobia
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- "Commercial whaling, especially for gray whales, *Eschrichtius robustus*, and humpback whales, *Megaptera novaeangliae*, at California and Baja California shore stations in the 19th century (1854-1899)," by Randall R. Reeves and Tim D. Smith, 1:1-25
- Congridae—see Eel, conger
- Crab
longspine swimming
deep-water bottom trawl survey, 4:20-25
- stilt spider
deep-water bottom trawl survey, 4:20-25

- swimming
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- tenspine spider
deep-water bottom trawl survey, 4:20-25
- yellow box
deep-water bottom trawl survey, 4:20-25
- Croaker, Atlantic
deep-water bottom trawl survey, 4:20-25
- Cutlassfish, Atlantic
deep-water bottom trawl survey, 4:20-25

D-E

- Dasyatis americana*—see Stingray, southern
- Dasyatis centroura*—see Stingray, roughtail
- Delphinus* spp.—see Dolphin, common
- Dogfish
smooth
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- spiny
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- Dolphin
bottlenose
central California survey, 1967-2007, 4:1-19
- common
central California survey, 1967-2007, 4:1-19
- northern right whale
central California survey, 1967-2007, 4:1-19
- Pacific white-sided
central California survey, 1967-2007, 4:1-19
- Risso's
central California survey, 1967-2007, 4:1-19
- Drum, red
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- Echeneis* sp.—see Sharksucker
- Eel
conger
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- king snake
bycatch in U.S. Atlantic bottom longline fishery, 2002-06, 2:34-38
- Epinephelus itajara*—see Grouper, goliath
- Epinephelus morio*—see Grouper, red
- Epinephelus niveatus*—see Grouper, snowy
- Eschrichtius robustus*—see Whale, gray
- Etrumeus teres*—see Herring, round

F

- Farfantepenaeus aztecus*—see Shrimp, brown

Fisheries management

- NMFS social science history, 2:14–33
- platform terminal transmitters/TED interactions, 3:44–47
- white shrimp, 2:1–13

Fisheries history

- gray whale catches
 - Baja California shore stations, 1:1–25
 - California shore stations, 1:1–25
 - eastern North Pacific, ship-based, 1:26–65
- humpback whale catches
 - Baja California shore stations, 1:1–25
 - California shore stations, 1:1–25
 - North Atlantic Ocean, 3:1–43
- National Marine Fisheries Service, NOAA sociocultural analysis, 2:14–33

Fisheries, commercial

- black clam, 3:48–61
- historical whaling, 1:1–65
- sablefish, 4:26–35

“Fishery-independent bottom trawl surveys for deep-water fishes and invertebrates of the U.S. Gulf of Mexico, 2002–08,” by Mark A. Grace, Brandi Noble, Walter Ingram, Adam Pollack, and Alonzo Hamilton, 4:20–25

Ford, Travis—see Morgan et al.

“Forty years of winter: Cetaceans observed during the southbound migration of gray whales, *Eschrichtius robustus*, near Granite Canyon, central California,” by Kim E.W. Shelden and David J. Rugh, 4:1–19

G–H

Gag

- bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

Galeocerdo cuvier—see Shark, tiger

Gear

- black clam fishery, 3:53–56
- platform terminal transmitters/TED interactions, 3:44–47

Ginglymostoma cirratum—see Shark, nurse

Grace, Mark A., Brandi Noble, Walter Ingram, Adam Pollack, and Alonzo Hamilton, “Fishery-independent bottom trawl surveys for deep-water fishes and invertebrates of the U.S. Gulf of Mexico, 2002–08,” 4:20–25

Grampus griseus—see Dolphin, Risso’s

Grouper

- black
 - bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38
- goliath
 - bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

red

- bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

snowy

- bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

Habitat

- black clam, 3:48–51

Hale, Loraine—see Morgan et al.

Hamilton, Alonzo—see Grace et al.

Hammerhead

great

- bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

scalloped

- bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38

Hart, Rick A.—see Nance et al.

Herring, round

- deep-water bottom trawl survey, 4:20–25

Higgins, Benjamin M.—see Seney et al.

“Historical catches of humpback whales, *Megaptera novaeangliae*, in the North Atlantic Ocean: Estimates of landings and removals,” by Tim D. Smith and Randall R. Reeves, 3:1–43

History—see Fisheries history

I–J–K

Illex coindetti—see Squid, southern shortfin

Illex oxygonius—see Squid, sharptail shortfin

Ingram, Walter—see Grace et al.

“Interactions between platform terminal transmitters and turtle excluder devices,” by Erin E. Seney, Benjamin M. Higgins, and Andre M. Landry, Jr., 3:44–47

Josephson, Elizabeth A.—see Reeves et al.

Karinen, John F., Harold J. Barnett, and Michele Masuda, “Soft flesh in sablefish, *Anoplopoma fimbria*, of southeastern Alaska: Relationships with depth, season, and biochemistry,” 4:26–35

L

Lagenorhynchus obliquidens—see

Dolphin, Pacific white-sided

Lagodon rhomboides—see Pinfish

Landings

humpback whale

- historical in North Atlantic Ocean, 3:1–43

- white shrimp size-composition, 2:1–13

Landry, Andre M., Jr.—see Seney et al.

Lebo, Susan A.—see Reeves et al.

Lepidochelys kempii—see Sea turtle, Kemp’s ridley

Lissodelphis borealis—see Dolphin, northern right whale

Litopenaeus setiferus—see Shrimp, white

Lizardfish, shortjaw

- deep-water bottom trawl survey, 4:20–25

Loligo pealeii—see Squid, longfin

Loligo plei—Squid, arrow

“The long voyage to including sociocultural analysis in NOAA’s National Marine Fisheries Service,” by Susan Abbott-Jamieson and Patricia M. Clay, 2:14–33

Lund, Judith N.—see Reeves et al.

Lutjanus analis—see Snapper, mutton

Lutjanus campechanus—see Snapper, red

M–N

Masuda, Michele—see Karinen et al.

Megalops atlanticus—see Tarpon

Megaptera novaeangliae—see Whale, humpback

Micropogonias undulatus—see Croaker, Atlantic

Mobula hypostoma—see Ray, devil

Mohamed, K. S.—see Suja and Mohamed

Morgan, Alexia, John Carlson, Travis

Ford, Laughling Sicheloff, Loraine Hale,

Mike S. Allen, and George Burgess,

“Temporal and spatial distribution of finfish bycatch in the U.S. Atlantic bottom longline shark fishery,” 2:34–38

Mustelis canis—see Dogfish, smooth

Mycteroperca bonaci—see Grouper, black

Mycteroperca microlepis—see Gag

Nance, James M., Charles W. Caillouet Jr., and Rick A. Hart, “Size-composition of annual landings in the white shrimp, *Litopenaeus setiferus*, fishery of the northern Gulf of Mexico, 1960–2006: Its trends and relationships with other fishery-dependent variables,” 2:1–13

National Marine Fisheries Service, NOAA sociocultural analysis, 2:14–33

Negaprion brevirostris—see Shark, lemon

“Nineteenth-century ship-based catches of gray whales, *Eschrichtius robustus*, in the eastern North Pacific,” by Randall R. Reeves, Tim D. Smith, Judith N. Lund, Susan A. Lebo, and Elizabeth A. Josephson, 1:26–65

Noble, Brandi—see Grace et al.

O–P–R

Octopus vulgaris—see Octopus, common

Octopus, common

- deep-water bottom trawl survey, 4:20–25

Ophichthus rex—see Eel, king snake

Orcinus orca—see Whale, killer

Parapenaeus setiferus—see Shrimp, rose

Penaeopsis serrata—see Shrimp, pink-speckled

Peprilus burti—see Butterfish, gulf

Phocoena phocoena—see Porpoise, harbor

Phocoenoides dalli—see Porpoise, Dall's
Pholidoteuthis adami—see Squid, pink scaled
 Pinfish
 deep-water bottom trawl survey, 4:20–25
Pleoticus rodustus—see Shrimp, royal red
 Pollack, Adam—see Grace et al.
 Porgy, longspine
 deep-water bottom trawl survey, 4:20–25
 Porpoise
 Dall's
 central California survey, 1967–2007, 4:1–19
 harbor
 central California survey, 1967–2007, 4:1–19
 Portunidae—see Crabs, swimming
Portunus spinicarpus—see Crab, longspine swimming
Pristipomoides aquilonaris—see Wenchmen
Rachycentron canadum—see Cobia
Raja eglanteria—see Skate, clearnose
 Ray
 cownose
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 devil
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 spotted eagle
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 Reeves, Randall R.—see Smith and Reeves
 Reeves, Randall R., and Tim D. Smith,
 "Commercial whaling, especially for gray whales, *Eschrichtius robustus*, and humpback whales, *Megaptera novaeangliae*, at California and Baja California shore stations in the 19th century (1854–1899)," 1:1–25
 Reeves, Randall R., Tim D. Smith, Judith N. Lund, Susan A. Lebo, and Elizabeth A. Josephson, "Nineteenth-century ship-based catches of gray whales, *Eschrichtius robustus*, in the eastern North Pacific," 1:26–65
Rhinoptera bonasus—see Ray, cownose
Rhizoprionodon terraenovae—see Shark, sharpnose
 Rugb, David J.—see Shelden and Rugb

S

Sablefish
 flesh quality, 4:26–35
Saurida normani—see Lizardfish, shortjaw
 Scad, rough
 deep-water bottom trawl survey, 4:20–25
 Scallop, paper
 deep-water bottom trawl survey, 4:20–25
Sciaenops ocellatus—see Drum, red

Sea turtle
 Kemp's ridley
 platform terminal transmitter/TED interactions, 3:44–47
 loggerhead
 platform terminal transmitter/TED interactions, 3:44–47
Semirossia equalis—see Bobtail, greater shining
 Seney, Erin E., Benjamin M. Higgins, and Andre M. Landry, Jr., "Interactions between platform terminal transmitters and turtle excluder devices," 3:44–47
 Shark
 Atlantic angel
 deep-water bottom trawl survey, 4:20–25
 blacknose
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 blacktip
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 bull
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 Caribbean reef
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 dusky
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 lemon
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 night
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 nurse
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 sandbar
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 sand tiger
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 sharpnose
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 silky
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 spinner
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 tiger
 bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38

Sharksucker
 bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38
 Shelden, Kim E.W., and David J. Rugb,
 "Forty years of winter: Cetaceans observed during the southbound migration of gray whales, *Eschrichtius robustus*, near Granite Canyon, central California," 4:1–19
 Shrimp
 brown
 deep-water bottom trawl survey, 4:20–25
 brown rock
 deep-water bottom trawl survey, 4:20–25
 humpback
 deep-water bottom trawl survey, 4:20–25
 pinkspotted
 deep-water bottom trawl survey, 4:20–25
 rose
 deep-water bottom trawl survey, 4:20–25
 royal red
 deep-water bottom trawl survey, 4:20–25
 white
 landings size-composition, 2:1–13
 Siceloff, Laughling—see Morgan et al.
Sicyonia brevirostris—see Shrimp, brown rock
 "Size-composition of annual landings in the white shrimp, *Litopenaeus setiferus*, fishery of the northern Gulf of Mexico, 1960–2006: Its trends and relationships with other fishery-dependent variables," by James M. Nance, Charles W. Caillouet, Jr., and Rick A. Hart, 2:1–13
 Skate, clearnose
 bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38
 Smith, Tim D.—see Reeves and Smith
 Smith, Tim D.—see Reeves et al.
 Smith, Tim D., and Randall R. Reeves,
 "Historical catches of humpback whales, *Megaptera novaeangliae*, in the North Atlantic Ocean: Estimates of landings and removals," 3:1–43
 Snapper
 mutton
 bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38
 red
 bycatch in U.S. Atlantic bottom longline fishery, 2002–06, 2:34–38
 "Soft flesh in sablefish, *Anoplopoma fimbria*, of southeastern Alaska: Relationships with depth, season, and biochem-

- istry," by John F. Karinen, Harold J. Barnett, and Michele Masuda, 4:26–35
- Solenocera vioscai*—see Shrimp, humpback
- Sphyrna lewini*—see Hammerhead, scalloped
- Sphyrna barracuda*—see Barracuda, great
- Sphyrna mokarran*—see Hammerhead, great
- Sphyrna tiburo*—see Bonnethead
- Squalus acanthias*—see Dogfish, spiny
- Squatina dumerili*—see Shark, Atlantic angel
- Squid
- arrow
 - deep-water bottom trawl survey, 4: 20–25
 - longfin
 - deep-water bottom trawl survey, 4: 20–25
 - pink scaled
 - deep-water bottom trawl survey, 4: 20–25
 - sharp-tail shortfin
 - deep-water bottom trawl survey, 4: 20–25
 - southern shortfin
 - deep-water bottom trawl survey, 4: 20–25
- Stenocionops spinosissimus*—see Crab, ten-spine spider
- Stenotomus caprinus*—see Porgy, longspine
- Stingray
- rough-tail
 - bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
 - southern
 - bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
- Suja, N., and K. S. Mohamed, "The black clam, *Villorita cyprinoides*, fishery in the State of Kerala, India," 3:48–61
- Surveys
- central California cetacean, 1967–2007, 4:1–19
 - fishery-independent bottom trawl, U.S. Gulf of Mexico
 - deep-water fishes, 4:20–25
 - invertebrates, 4:20–25
- T–V–W**
- Tarpon
- bycatch in U.S. Atlantic bottom long-line fishery, 2002–06, 2:34–38
- "Temporal and spatial distribution of fin-fish bycatch in the U.S. Atlantic bottom longline shark fishery," by Alexia Morgan, John Carlson, Travis Ford, Laughling Siceloff, Loraine Hale, Mike S. Allen, and George Burgess, 2:34–38
- Tona galea*—see Tun, giant
- Trachurus lathami*—see Scad, rough
- Trichiurus lepturus*—see Cutlassfish, Atlantic
- Tun, giant
 - deep-water bottom trawl survey, 4:20–25
- Tursiops truncatus*—see Dolphin, bottle-nose
- Villorita cyprinoides*—see Clam, black
- Wenchmen
 - deep-water bottom trawl survey, 4:20–25
- Whale
- blue
 - central California survey, 1967–2007, 4:1–19
 - gray
 - southbound migration census, 1967–2007, 1:1–19
 - humpback
 - central California survey, 1967–2007, 4:1–19
 - historical commercial landings, 1:1–65; 3:1–43
 - killer
 - central California survey, 1967–2007, 4:1–19
 - minke
 - central California survey, 1967–2007, 4:1–19

Papers in the *Marine Fisheries Review* 72(1-4), 2010

72(1)

"Commercial whaling, especially for gray whales, *Eschrichtius robustus*, and humpback whales, *Megaptera novaeangliae*, at California and Baja California shore stations in the 19th century (1854-1899)," by Randall R. Reeves and Tim D. Smith, 1:1-25

"Nineteenth-century ship-based catches of gray whales, *Eschrichtius robustus*, in the eastern North Pacific," by Randall R. Reeves, Tim D. Smith, Judith N. Lund, Susan A. Lebo, and Elizabeth A. Josephson, 1:26-65

72(2)

"Size-composition of annual landings in the white shrimp, *Litopenaeus setiferus*, fishery of the northern Gulf of Mexico,

1960-2006: Its trends and relationships with other fishery-dependent variables," by James M. Nance, Charles W. Caillouet, Jr., and Rick A. Hart, 2:1-13

"The long voyage to including sociocultural analysis in NOAA's National Marine Fisheries Service," by Susan Abbott-Jamieson and Patricia M. Clay, 2:14-33

"Temporal and spatial distribution of finfish bycatch in the U.S. Atlantic bottom long-line shark fishery," by Alexia Morgan, John Carlson, Travis Ford, Laughling Siceloff, Loraine Hale, Mike S. Allen, and George Burgess, 2:34-38

72(3)

"Historical catches of humpback whales, *Megaptera novaeangliae*, in the North Atlantic Ocean: Estimates of landings

and removals," by Tim D. Smith and Randall R. Reeves, 3:1-43

"Interactions between platform terminal transmitters and turtle excluder devices," by Erin E. Seney, Benjamin M. Higgins, and Andre M. Landry, Jr., 3:44-47

"The black clam, *Villorita cyprinoides*, fishery in the State of Kerala, India," by N. Suja and K. S. Mohamed, 3:48-61

72(4)

"Forty years of winter: Cetaceans observed during the southbound migration of gray whales, *Eschrichtius robustus*, near Granite Canyon, central California," by Kim E.W. Shelden and David J. Rugh, 4:1-19

"Fishery-independent bottom trawl surveys for deep-water fishes and invertebrates of the U.S. Gulf of Mexico, 2002-08," by Mark A. Grace, Brandi Noble, Walter Ingram, Adam Pollack, and Alonzo Hamilton, 4:20-25

"Soft flesh in sablefish, *Anoplopoma fimbria*, of southeastern Alaska: Relationships with depth, season, and biochemistry," by John F. Karinen, Harold J. Barnett, and Michele Masuda, 4:26-35

Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed double-spaced throughout and submitted with two duplicate copies. The complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e. there can be no subdivision without at least two items).

Style

The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms,

abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (1984 ed.) and the CBE Style Manual (5th ed.) for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 Nov. 1991. Measurements should be expressed in metric units, e.g. metric tons as t; other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lowercase el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g. nine fish but 9 mm).

Footnotes

Footnotes should not be embedded within the text document. They must be numbered with Arabic numerals and typed on a separate sheet of paper. Footnote all personal communications, listing the name, affiliation, and address of the communicator and date of communication. Unpublished data and unpublished manuscripts should include the title, author, pagination of the manuscript or report, and the address where it is on file. Authors are advised to avoid references to non-standard (gray) literature, such as internal, project, processed, or administrative reports, wherever possible. Where these references are used, please include whether they are available from NTIS (National Technical Information Service) or from some other public depository.

Literature Cited

Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted.

Citations should be double-spaced and listed

alphabetically by the senior author's surname and initials. Coauthors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1979a, 1979b, 1979c, etc.). Authors must double-check all literature cited; they alone are responsible for its accuracy.

Tables

Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but sufficient to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

Figures

Figures include line illustrations and photographs (or slides) and must be cited in numerical order in the text. Figures are to be labeled with author's name and number of figure. Use Times Roman font (upper and lowercase letters) to label within figures. Avoid vertical lettering except for y-axis labels. Zeros should precede all decimal points for values less than one. Figures should be submitted as both laser-printed copies and computer software files. Figure legends should explain all symbols and abbreviations and should be double-spaced on a separate page at the end of the manuscript. Consider column and page sizes when designing figures. Please note that we do not print graphics in color.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript to:

Editor, *Marine Fisheries Review*
Scientific Publications Office
National Marine Fisheries Service, NOAA
7600 Sand Point Way N.E.
Seattle, WA 98115

UNITED STATES
DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
SCIENTIFIC PUBLICATIONS OFFICE
SEATTLE, WA 98115

PRESORT STANDARD
US POSTAGE
PAID
ALBUQUERQUE, NM
PERMIT NO. 388

